MWH
STANDARD OPERATING PROCEDURES

SOP-1
DRILLING METHODS

MWH
MONTGOMERY WATSON HARZA

STANDARD OPERATING PROCEDURES
DRILLING METHODS

TABLE OF CONTENTS

1.0 INTRODUCTION

Drilling is a common activity associated with all phases of environmental investigations. Drilling methods are most commonly used to collect site data during investigations and studies, but are also used to install vapor extraction or water wells associated with remedial actions, treatability studies, or pilot studies.

Field investigations usually require invasive types of activities to gather information to evaluate the site. The investigation may require the analysis of soil and/or groundwater samples that would be collected by drilling a borehole. Many times the borehole is converted into a well for the evaluation of vapor or groundwater conditions over time. In addition to the collection of samples for analyses, other data such as physical parameters of soils can be obtained from boreholes.

For determining the most appropriate drilling method for investigations or studies, primary consideration must be given to obtaining information that is representative of existing conditions and the collection of samples that are valid for chemical analysis. The samples must not be contaminated or adversely affected by the drilling method.

Drilling associated with remedial actions, pilot studies, or treatability studies may include the installation of vapor or water extraction and/or injection wells. In selecting the most appropriate drilling method for these projects, primary consideration must be given to completion of a well that will perform as designed.

This SOP provides a description of the principles of operation and the applicability and implementability of standard drilling methods used during field investigations. The purpose of this document is to aid in the selection of drilling methods that are appropriate for site-specific conditions. It is intended to be used by the Project Manager (PM), Project Engineer (PE), Field Team Leader (FTL), and site hydrogeologist to develop an understanding of each method sufficient to permit work planning, scheduling, subcontracting, and resource planning.

This document focuses on methods and equipment that are readily available and typically applied. It is not intended to provide a comprehensive discussion of drilling methods. Two general drilling methods are discussed: (1) methods that do not use circulating fluids, and (2) methods requiring the circulation of drilling fluids to transport cuttings to the surface.

2.0 DEFINITIONS

Bailer

A cylindrical tool designed to remove material, both solid and liquid, from a well or borehole. A valve at the bottom of the bailer retains the material in the bailer. The three types of bailers are flat-valve bailer, a dart-valve bailer, and the sand pump with rod plunger.

Cone Penetrometer

An instrument used to identify the underground conditions by measuring the differences in the resistance and other physical parameters of the strata. The cone penetrometer consists of a conical point attached to a drive rod of smaller diameter. Penetration of the cone into the formation forces the soil aside, creating a complex shear failure. The cone penetrometer is very sensitive to small differences in soil consistency.

Cuttings

Formation particles obtained from a borehole during the drilling process.

Drilling Fluids or Muds

A water-based or air-based fluid used in the well drilling operation to remove cuttings from the borehole, to clean and cool the bit, to reduce friction between the drill string and the sides of the borehole, and to seal the borehole.

Dual-Purpose Well

A well that can be used as both a monitoring and extraction or injection well.

Flight

A individual auger section, usually 5 feet in length.

Heaving Formation

Unconsolidated saturated substrate encountered during drilling where the hydrostatic pressure of the formation is greater than the borehole pressure causing the sands to move up into the borehole.

Kelly Bar

A hollow steel bar or pipe that is the main section of drill string to which the power is directly transmitted from the rotary table to rotate the drill pipe and bit. The cross section of the kelly is either square, hexagonal, or grooved. The kelly works up and down through drive bushings in the rotary table.

Pitch

The distance along the axis of an auger flight that it takes for the helix to make one complete 360-degree turn.

Rotary Table

A mechanical or hydraulic assembly that transmits rotational torque to the kelly, which is connected to the drill pipe and the bit. The rotary table has a hole in the center through which the kelly passes.

Split-Spoon Sampler

A thick-walled steel tube split lengthwise used to collect soil samples. The sampler is commonly lined with metal sample sleeves and is driven or pushed downhole by the drill rig to collect samples.

Thin-Walled Sampler

A sampling devise used to obtain undisturbed soil samples made from thin-wall tubing. The sampler is also known as a Shelby tube. The thin-wall sampler minimizes the most serious sources of disturbance: displacement and friction.

3.0 RESPONSIBILITIES

Project Manager

Selects site-specific drilling methods with input from the Field Team Leader and Site Hydrogeologist, and oversees and/or prepares drilling subcontracts.

Site Hydrogeologist

Selects site-specific drilling options. Helps prepare technical provisions of drilling subcontracts.

Field Team Leader

Implements selected drilling program. Aids in the selection of drilling methods and preparation of subcontracts.

4.0 DRILLING METHODS

Drilling methods can be separated into two general types; techniques that use circulating fluids and techniques that do not use circulating fluids. The following section discusses the drilling methods that fall into these two general categories.

4.1 METHODS WITHOUT CIRCULATING FLUIDS

4.1.1 Augering

Auger drilling is accomplished by rotating a pipe or rod that has a cutting bit. The common auger drilling methods discussed in this section are hand, continuous-flight, hollow-stem, and bucket.

4.1.1.1 Hand Auger. A hand auger typically cuts a hole 3 to 9 inches in diameter and, depending on the geologic materials, may be advanced to about 15 feet. Generally, the borehole cannot be advance below the water table because the hole collapses. Soil samples for chemical or geotechnical analyses should not be collected directly from a hand auger because the samples are disturbed and cross contamination may occur. Samples for chemical or geotechnical analyses should be taken with a sampling tool such as a drive sampler applied at the desired depth. Samples for lithologic logging purposes may be taken directly from the auger.

Applications	Limitations
• Shallow soil investigations • Soil samples • Water-bearing zone identification	• Limited to very shallow depths • Unable to penetrate dense or rocky soil • Borehole stability difficult to maintain • Labor intensive

4.1.1.2 Continuous-Flight Augers. Continuous-flight augers consist of a plugged tubular steel center shaft around which is welded a continuous steel strip in the form of a helix. An individual auger is known as a "flight" and is generally 5 feet long. Auger drill heads are generally designed to cut a hole 10 percent greater in diameter than the actual diameter of the auger they serve. In addition to diameter, augers are specified by the pitch of the auger and the shape and dimension of the connections.

Applications	Limitations
• Shallow soils investigations • Soil samples • Vadose zone monitoring wells • Monitoring wells in saturated, stable soils • Identification of depth to bedrock • Fast and mobile	• Soil sampling difficult and limited to areas of stable soils • Difficult to build monitoring wells in unstable soils • Depth capability decreases as diameter of auger increases • Monitoring well diameter limited by auger diameter

4.1.1.3 Hollow-Stem Augers. Hollow-stem augers are commonly used in unconsolidated materials to depths of about 150 feet. An advantage of this method is that undisturbed soil samples can be collected and the augers act as a temporary outer casing when installing a monitoring well.

Hollow-stem augers are generally made of two pieces: an annular outer head attached to the bottom of the lead auger and an inner pilot or center bit mounted in a plug which is removable from the center of the auger to the surface. The removable inner plug is the primary advantage of this drilling method. Withdrawing the plug while leaving the auger in place provides an open, cased hole into which samplers, down-hole drive hammers, instruments, casing, wire, pipe, or numerous other items can be inserted. Replacing the center bit and plug allows for continuation of the borehole.

Hollow-stem augers are specified by the inside diameter of the hollow stem, not by the hole size it drills. Hollow-stem augers are available with inside diameters of 2.5, 3.25, 3.375, 4.0, 4.25, 6.25, 6.625, 8.25, and 10.25 inches. The most commonly used sizes are 3.25 inches and 4.25 inches for 2-inch monitoring wells and 6.625 inches for 4-inch monitoring wells. The larger diameter augers, 8.25 and 10.25 inches, are not generally used for monitoring well installation although they have been utilized for the installation of dual-purpose wells.

The rotation of the augers causes the cuttings to move upward and be "smeared" along the borehole walls. This smearing may effectively seal off the upper zones thereby reducing the possibility of cross contamination of the upper zones to the deeper zones but increases the possibility of deep to shallow contamination.

Drilling speed with hollow-stem augers is dependent upon the types of materials encountered. Heavy formations such as "fat" clays should be drilled at 30 to 50 revolutions per minute (rpm). Good clean sand that will stand open can be successfully augered at 75 rpm.

Applications	Limitations
• All types of soils investigations • Permits good soil sampling with split-spoon or thin-wall samplers • Monitoring well installation in all unconsolidated formations • Can serve as temporary casing • Can be used in stable formations to set surface casing	• Difficulty in preserving sample integrity in heaving formations • Formation invasion by water or drilling mud if used to control heaving • Possible cross contamination of aquifers where annular space not positively controlled by water or drilling mud or surface casing • Limited diameter of augers limits casing size • Smearing of clays may seal off aquifer to be monitored

4.1.1.4 Bucket Auger. Bucket augers have depth capacity of 30 to 75 feet and are used for large diameter holes of about 16 to 48 inches. Most bucket augers are "gravity fed" and are used for vertical holes. They are not normally used to drill monitoring wells or for soil sampling but may be used to drill production and recovery wells. They may also be used to set conductor or surface casings for production wells.

Generally, the auger bucket advances into the formation by combination of dead weight and the tooth cutting angle. The auger cuts into the formation about 1 to 2 feet at a time, filling the auger bucket. The bucket is attached to the lower end of a kelly bar that passes through and is rotated by a large ring gear that serves as a rotary table. The kelly is square in cross section and consists of two or more lengths of square tubing, one length telescoped inside the other. When the bucket is withdrawn from the hole by means of a wire-line hoist cable, it is swung to the side of the hole and the spoil is dumped out through the bottom by means of a hinge and latch device on the bucket bottom.

Applications	Limitations
• Drilling of large diameter boreholes to a maximum depth of 75 feet • Drilling in unconsolidated formations	• Difficult to advance the borehole below the water table • Consolidated formations and cobbles are difficult to drill • Loose sand formations may slough during drilling

4.1.2 Percussion Drilling

Percussion drilling is a form of drilling in which the basic method of advance is hammering, striking, or beating on the formation. Common percussion methods that do not use circulating fluids are cable-tool, driven boreholes, and rotosonic drilling.

4.1.2.1 Cable-Tool Drilling. Cable-tool operates by alternately raising and dropping a bit, hammer, or other heavy tool. In consolidated formation, the drill bit breaks or crushes the formation. In unconsolidated formations, the drill bit primarily loosens when drilling. In both instances, the reciprocating action of the tools mixes the crushed or loosened particles with water to form a slurry or sludge at the bottom of the borehole. If little or no water exists in the penetrated formation, water is added to form the slurry. Slurry accumulation increases as drilling proceeds and eventually it reduces the impact of the tools. When the drop of the string of tools is hindered by the thickened slurry, the slurry is removed by a bailer. Water is then added, if needed, and drilling resumes.

Most boreholes drilled in unconsolidated formations are drilled "open hole", that is, no casing is used during part or all of the drilling operation. Drilling in unconsolidated formations differs from hard-rock drilling as pipe or well casing must follow the drill bit closely as the well is deepened to prevent caving and to keep the borehole open.

Using the cable-tool drilling technique in monitoring work is limited because the method is slow. Drilling rates of 20 to 100 feet per day are typical with the average being approximately 50 feet per day. Holes much smaller than 6-inches are impractical because of the need for a relatively large, heavy bit. The method does not use drilling muds but does allow sampling of groundwater with a drive and bail technique as the hole is advanced in high-yielding formations.

Applications	**Limitations**
• Drilling in all types of geologic formations • Almost any depth and diameter range • Ease of monitoring well installation • Ease and practicality of well development • Excellent samples of geologic materials	• Drilling relatively slow • Heaving of unconsolidated materials must be controlled • Equipment availability more common in central, north central and northeast sections of the United States

4.1.2.2 Driving. A borehole can be constructed by driving a solid probe or plugged pipe into the ground. The information obtained by this technique can be either minimal or extensive.

Driven wells, commonly referred to as wellpoints, are driven into the ground by hand or with heavy drive heads mounted on a tripod, drill rig derrick, or similar hoisting device. Wellpoints consist of a wellpoint (screen) that is attached to the bottom of a casing. Wellpoint and casing diameters generally range from 1.25 to 2 inches. Depths of 30 feet can be achieved by hand in sands or sands and gravels with thin clay seams. Depths of 50 feet or more can be achieved in loose soils with hammers weighing up to 1,000 pounds.

Driving through dense silts and clays and/or bouldery silts and clays is often extremely difficult or impossible. The well point may not be structurally strong enough and may be damaged or destroyed by driving through dense soils. Additionally, the screen may become plugged when driving through silts and clays and may be very difficult to reopen during development. Soil samples cannot be collected during this process; however, crude stratigraphic information may be obtained by recording the number of blows per foot of penetration. Driven wells or well points are usually installed for the collection of groundwater samples and the determination of static water levels to establish the regional groundwater gradient.

A large track-mounted backhoe (CAT 245) has been used to install extraction wells in a landfill to the 30-foot depth. The bucket of the backhoe is used to push a 6-inch-diameter drive pipe with a plugged bottom. When the drive pipe reaches the final depth for the well, the plug at the bottom of the drive pipe is removed and the well screen and casing materials are placed inside the drive pipe. A large 50-ton crane then pulls the drive pipe, leaving the well materials in the borehole. This technique is highly dependent upon the geologic formation and required depth. The drive pipe pushes the formation aside. This can cause a compaction of the formation, which could impact the performance of the well.

Considerably more information can be obtained by driving a penetrometer or a Dutch Cone. Penetration of the soil with a cone forces the soil aside, creating a complex shear failure. The degree of resistance yields the geologic logs of the borehole. Penetrometers can also obtain groundwater samples and possibly soil samples. The borehole that the penetrometer makes is usually abandoned; however, occasionally a small-diameter piezometer can be constructed within the borehole. For more information on cone penetrometer testing, see the Standard Operating Procedures on CPT.

Applications	Limitations
• Drilling of a borehole when soil samples are not needed • Installation of a shallow well point when there are site access and work place limitations	• Geologic formations must be conducive for driven wells • Driven wells should be limited to shallow wells • Formation compaction usually occurs that can affect well production

4.1.2.3 Rotasonic Drilling. Rotasonic drilling, also known as resonance drilling, is a percussion drilling technique that uses a high-frequency drive hammer. The frequency of the drive hammer varies from 150 to 250 hits per minute. The drive pipe is either closed bottom or fitted with a soil-sampling tube. If the bottom of the drive pipe is closed, the borehole is made without the removal of any formation. Instead, the formation is literally pushed to the side and out of the way of the drive pipe, which acts as well casing as the boring proceeds. The high frequency of the hammer tends to liquefy the formation in the vicinity of the bit, thus reducing the degree of difficulty of pushing pipe into the formation.

A soil sampling device, such as a split-spoon sampler or a core barrel, can be placed inside the drive pipe in lieu of the end plug. The sampler is removed at 5- or 10-foot intervals and replaced with an empty sampler. This procedure yields a continuous soil sample and produces minimal waste as only the formation within the sampler is brought to the surface. A monitoring well can be installed in the borehole by removing the sampler and setting the well screen and casing inside the drive pipe. The drive pipe is then withdrawn. This drilling technique again pushes the formation aside to create the borehole. Certain formation compaction can occur which could impact the performance of a well. Additionally, the rate of penetration of the drive pipe is very high, producing considerable heat at the bit on the drive pipe and within the sampler. The heat in the sampler may have a detrimental effect on soil samples for chemical analysis.

Applications	Limitations
• Rapid drilling technique especially in difficult drilling formations • Use when drilling in contaminated areas and disposal costs for wastes are high • Can obtain continuous core	• Very limited equipment availability • Heat generated with drive pipe can compromise soil samples • Formation compaction usually occurs that can affect well production

4.2 METHODS WITH CIRCULATING FLUIDS

Many drilling techniques uses a circulating fluid, such as water or drilling mud, gas such as air, or a combination of air, water, and a surfactant to create foam. Circulation fluids flow from the surface either through the drill pipe, out through the bit, and up the annulus between the borehole wall and the drill pipe (direct rotary) or down the borehole annulus, into the bit, and up the drill pipe (reverse rotary). Generally the up-hole velocity needed to transport cuttings to the surface is between 100 to 150 feet per minute for plain water with no additives, 80 to 120 feet per minute for high-grade bentonite drill muds, 50 to 1,000 feet per minute for foam drilling, and up to 3,000 feet per minute for air with no additives. Additives decrease the required minimum velocity. Excessive velocities can cause erosion of the borehole wall.

The use of circulating fluids may involve the addition of chemicals to the borehole. Drilling mud utilizes bentonite clay and possibly polymers. Additives to air drilling may include surfactants (detergents) and water mist to generate foam. Compressed air may also contain various amounts of hydrocarbon lubricants. Therefore, attention should be given to the circulating fluids and any possible additives that are used when using drilling methods utilizing circulation fluids.

4.2.1 Rotary Drilling Methods

Rotary drilling methods requires the rotation of the drill pipe and the drill bit to advance the borehole. The common drilling methods that uses circulating fluids to remove the drill cuttings from the borehole are presented in the following sections.

4.2.1.1 Conventional Mud Rotary Drilling. In conventional mud rotary drilling, the circulating fluid is pumped from the surface through the rotating drill pipe and bit to flush cuttings to the surface. At the surface the fluid is directed into a circulation pit or tank where the cuttings settle out. The circulating fluid is then picked up with the mud pump and again directed downhole. Bentonite is usually added to water to make the drilling mud or fluid. The functions of the drilling fluid are to:

1. Lift the cuttings from the bottom of the borehole and carry them to a settling pit.
2. Support and stabilize the borehole wall to prevent caving.
3. Seal the borehole wall to reduce fluid loss.
4. Cool and clean the drill bit.
5. Allow the cuttings to drop out in the settling pit.
6. Lubricate the bit, cone bearings, mud pump, and drill pipe.

For effective rotary drilling, the down force on the bit should be great enough to cause continuous penetration of the boring. The pounds per inch of bit weight depends upon the configuration of the bit and the formation being penetrated. Rotary speeds are generally in the range of 60 to 200 RPM.

Applications	Limitations
• Rapid drilling of clay, silt and reasonably compacted sand • Allows split-spoon and thin-walled samples in unconsolidated materials • Allows core sampling in consolidated rock • Drilling rigs widely available • Abundant and flexible range of tool sizes and depth capabilities • Very sophisticated drilling and mud programs available • Geophysical borehole logs	• Difficult to remove drilling mud and wall cake from borehole wall during development • Bentonite and other drilling additives may influence quality of groundwater samples • Circulated samples poor for monitoring well screen selection • Split-spoon and thin-wall samplers are expensive and of questionable cost effectiveness at depths greater than 150 feet • Wireline coring techniques for sampling both unconsolidated and consolidated formations often not available locally • Difficult to identify aquifers • Drilling fluid invasion of permeable zones may compromise validity of subsequent monitoring well samples

4.2.1.2 Air Rotary Drilling. In air rotary drilling, the circulation fluid is compressed air or a mixture of compressed air, a surfactant, and water mist, which creates a foam. As in conventional mud rotary, the drilling fluid is forced through the rotating drill pipe and bit to flush cuttings to the surface. At the surface the fluid is directed into a pit or storage container. The up-hole velocity of the air and cuttings should be approximately 3,000 feet per minute. This drilling method is primarily used in consolidated formations due to the fact that the rapidly rising cuttings would cause considerable erosion of the borehole wall in unconsolidated formations. With the air rotary drilling method, the circulating fluid is not reused again. The functions of the drilling fluid are to:

1. Lift the cuttings from the bottom of the borehole and carry them to the surface.
2. Cool and clean the drill bit.
3. Lubricate the bit, cone bearings, mud pump, and drill pipe.

Rotary speeds are generally in the range of 75 to 200 rpm. If the hardness of the formation increases to the point that roller-cone rock bits cannot successfully penetrate the formation, then a down-hole air hammer is used to penetrate the formation. The rotating speed using the down-hole air hammer is in the range of 15 to 30 rpms.

Applications	Limitations
• Rapid drilling of semi-consolidated and consolidated rock • Good quality/reliable formation samples • Equipment generally available • Allows easy and quick identification of lithologic changes • Allows identification of most water bearing zones • Allows estimation of yields in strong water-producing zones with short "down time"	• Surface casing frequently required to protect top of hole • Drilling restricted to semi-consolidated and consolidated formations • Samples reliable but occur as small particles that are difficult to interpret • Drying effect of air may mask lower yield water producing zones • Air stream requires contaminant filtration • Air may modify chemical or biological conditions. Recovery time uncertain

4.2.1.3 Air Rotary Casing Hammer (Drill and Drive). This method combines percussion and air rotary drilling methods to drill in unconsolidated formations. The borehole is drilled with the air rotary drilling method. Casing or drive pipe follows closely behind the rotary bit to prevent the erosion of the borehole wall. The casing is driven similar to a pile driver except for a hole through its axis through which a drill pipe is inserted and rotated. The drill bit is usually extended approximately 1-foot below the bottom of the drive pipe that acts as temporary casing.

Applications	Limitations
• Rapid drilling of unconsolidated sands, silts, and clays • Drilling in alluvial materials (including boulder formations) • Casing supports borehole thereby maintaining borehole integrity and minimizing inter-aquifer cross contamination • Eliminates circulation problems common with direct mud rotary method • Good formation samples	• Thin, low pressure water bearing zones easily overlooked if drilling not stopped at appropriate places to observe whether or not water levels are recovering • Samples pulverized as in all rotary drilling • Air may modify chemical or biological conditions • Difficult to obtain soil samples for chemical analysis

• Minimal formation damage as casing pulled back	

4.2.1.4 Center Stem Recovery Rotary Drilling (Reverse Circulation). In reverse circulation drilling, the circulating fluid (water) flows from the surface down the borehole annulus outside the drill pipe, into the drill bit, and up the inside of the drill pipe to ground surface. The fluid carries the cuttings to the surface and discharges them into a settling pit or tank. Reverse circulation is especially advantageous in very large boreholes and also in those cases where the erosive velocity of conventional rotary circulation would be detrimental to the borehole wall. Drilling is accomplished typically with water without additives. A large and dependable water supply is required to keep the borehole full of drilling fluid to maintain sufficient hydrostatic head on the borehole walls to prevent sloughing. Reverse circulation has few applications in monitoring work except when nested wells are desired. Production wells with 18- to 24-inch-diameter casing are typically drilled by the reverse circulation drilling method. Typical borehole diameters range from 15 to 36 inches; however, 60-inch-diameter boreholes are not uncommon.

Applications	Limitations
• Large capacity production wells • Nested wells • Normally does not use drilling muds (little if any mud cake is formed on the wall of the borehole) • Drills best in unconsolidated sands, silts, and clays	• Requires large and dependable source of water during drilling and well installation • Cobbles and bedrock are difficult to drill

4.2.1.5 Dual-Tube Rotary. Dual-tube rotary is an exploratory drilling technique utilizing two concentric drill pipes. Both drill pipes are rotated during drilling. The outside of the outer drill pipe is typically 4.5 inches. The diameter of the borehole is approximately 5 inches. Compressed air is forced between the two drill pipes and is directed to the center pipe at the bit. The cuttings are carried to the surface by the returning air at a velocity of approximately 3,000 feet per minute. This is an excellent drilling method to identify lithology and the locations of aquifers in deep boreholes. It is very difficult to obtain undisturbed soil samples for chemical or geotechnical analyses; however, groundwater samples can be obtained as aquifers are encountered. Geophysical logs can be obtained if the borehole is filled with drilling mud as the drill pipe is removed. Monitoring wells are typically not installed in dual-tube rotary boreholes unless the borehole is reamed out by the mud rotary method. Depths of 1,000 feet are not uncommon for this drilling method and typically, the more consolidated the formation, the better the drilling, as unconsolidated formations cause more drag or friction on the outside of the rotating drill pipe.

Applications	Limitations
• Used mostly for exploratory boreholes • Rapid extraction of drill cuttings from the borehole • Drill cuttings are representative of formation • Very rapid penetration rate in all formations • Can collect groundwater samples as aquifers are encountered	• Equipment availability • Cannot obtain undisturbed soil samples for chemical analysis • Borehole size is limited (5 inches)

4.2.2 Dual-Tube Percussion Drilling

Dual-tube percussion drilling is very similar to dual-tube rotary with the exception that the two drive pipes do not rotate during drilling. The two concentric drive pipes are driven into the ground with a hammer. The hammer is similar to units on pile drivers. The typical outside diameter of the outer drive pipe is 9 to 12 inches. The typical inside diameter of the inner pipe, where well materials would be inserted, is 6 to 8 inches. This drilling system is also a center stem recovery system. This drilling technique has been developed and is used primarily in hazardous waste investigations. This method is rapid and effective to depths of about 250 feet.

The outer pipe effectively seals off the formation while drilling, reducing the chance of cross contamination. Air is pumped between the annulus of the two pipes to the bit where it is deflected upward into the center pipe. Cuttings are transported to the surface through the center pipe.

In general, three systems are available: 7-inch OD/4.25-inch ID, 9-inch OD/6-inch ID, and 12-inch OD/8-inch ID. A 2-inch-diameter monitoring well can be constructed in the 7-inch system, a 4-inch-diameter monitoring well can be constructed in the 9-inch system, and a 5- or 6-inch-diameter monitoring well can be constructed in the 12-inch system.

Applications	Limitations
• Very rapid drilling through both unconsolidated and consolidated formations • Allows continuous sampling for lithologic logging in all types of formations • Very good representative samples can be obtained with minimal risk of contamination of sample and/or water bearing zone • In stable formations, wells with diameters as large as 6 inches can be installed in open hole completions • Soil samples can be easily obtained for chemical analysis	• Limited borehole size that limits diameter of monitoring wells • In unstable formations wells are limited to approximately 4 inches • Equipment availability more common in the southwest • Air may modify chemical or biological conditions; recovery time is uncertain

4.2.3 Suction Drilling

Suction drilling has been used to drill into consolidated formations that yield little if any groundwater. This is an experimental drilling method that has been used by the USGS to drill in basalts in Idaho. The drilling technique is very similar to the reverse circulation drilling technique discussed in Section 4.2.1.4 with the exception that air is circulating, not water. To drill the borehole, a drill rig rotates a modified air rotary bit at the end of the drill pipe. The cuttings are removed by the suction from a high-pressure, high-volume air and steam ejector/eductor siphon system. The suction is directed to the interior of the drill pipe. All formation cuttings, including formation fluids, are brought to the surface via the interior of the drill pipe.

To drill a 10-inch-diameter borehole, two 600 cfm/250 psi air compressors are connected parallel to the ejector/eductor siphon device. The suction from the siphon device is directed to the 2-3/8-inch-diameter drill pipe. A 1.5-horsepower blower fan is used to direct air down the borehole.

Applications	Limitations
• Allows continuous sampling for lithologic logging • Very good representative samples can be obtained • Drilling is not impeded in fractured formations that typically cause lost circulation problems	• Formations must be very consolidated to prevent the borehole wall from sloughing during drilling • Cuttings are very abrasive to the drill pipe and discharge lines • Difficult to maintain an adequate vacuum as air leaks form easily at threaded joints of the drill pipe • Groundwater could prevent the advancement of the borehole

The drilling contractor had numerous mechanical problems advancing the borehole to the 180-foot depth. Vacuum leaks caused a loss in suction and a plugging of the drill pipe. The drill pipe twisted off numerous times and the abrasive cuttings wore holes in hoses and pipes. This drilling method has some unique advantages; however, until the mechanical problems are solved, this technique will not be available for use.

5.0 CONSIDERATIONS FOR SELECTION OF DRILLING METHODS

Each project or drilling site has its own considerations for the selection of a particular drilling method. Prior to selecting a drilling method, several factors must be considered. The major factors that this section will address include the objective of the drilling program, site conditions, wastes generated, and client preferences. Other factors would include drilling costs, availability of trained crews and appropriate equipment, and project schedule requirements. Recognize that it may be very difficult to fulfill all of the sampling/drilling objectives with a single drilling method. The drilling method selected may compromise some of the objectives of the drilling program.

5.1 DRILLING OBJECTIVES

The primary considerations in selecting any drilling method is to ensure the selected method is capable of meeting the objective(s) of the drilling/sampling program. It is common to have more than one objective for the drilling/sampling program and it may be difficult to satisfy all the program objectives.

If sample collection (soil or groundwater) is the objective, the selected method must be capable of collecting, in an appropriate and approved manner, the necessary samples. Additionally, the contaminants of concern may have an influence on the drilling and sampling method.

If the objective of the drilling program is to install vapor or groundwater extraction wells, the selected method must be suitable for the installation of the designed well. It is important to not only consider the physical limitations of a particular drilling technique (i.e., depth and diameter), but examine the consequences of the drilling method with the drilling objective (i.e., smearing of the borehole walls rendering wells ineffective or inefficient).

If one of the objectives of the drilling program is to identify the different water-bearing zones, the drilling method must be able to accomplish this task.

5.2 SITE CONDITIONS

Site conditions can limit the drilling methods available for a particular program. Site conditions to be considered include both subsurface and surface conditions.

5.2.1 Subsurface Conditions

The subsurface stratigraphy of a site is a fundamental consideration when selecting a particular drilling method. The drilling equipment selected must be capable of effectively and economically penetrating the strata at the site to meet the project objectives. Particular stratigraphy which may pose problems for certain drilling methods include tight clayey soils, swelling clays, flowing sands, caliche, gravels, cobbles, lost circulation zones, and bedrock.

In addition to stratigraphy, the site hydrology must also be considered. If multiple water-bearing zones are expected, a conductor casing may be needed to seal off shallow water-bearing zones and prevent potential cross contamination. The need for conductor casings can affect the selection of a particular drilling method. Wells that deeply penetrate aquifers can also affect the selection of a particular drilling method.

5.2.2 Surface Conditions

Surface conditions can affect access to the site and the amount of available work space (both horizontal and vertical or overhead space). These in turn can affect the selection of a particular method or type of drill rig. Limited access and work space may require smaller or remotely powered drill rigs. The site terrain is a very important factor in choosing the drilling method as it is very expensive and difficult to mobilize large and/or heavy equipment over rugged terrain. For sites such as these, drill rigs (typically hollow-stem auger) are mounted on all-terrain equipment.

In addition to access and work space, the work environment must also be considered. This includes both weather and other site activities. Extremely hot or cold climates may require use of special drilling equipment or methods. Sites such as refineries where explosive atmospheres could exist may also require very special equipment. All site activities must also be considered as they may impact the selection of the drilling method.

5.3 WASTE GENERATION

Drilling operations typically generate significant volumes of waste that must be handled, stored, and eventually disposed. This is of particular concern when drilling into contaminated or hazardous materials. The type and volume of wastes generated during drilling differs for different drilling methods. The different handling and disposal requirements of drilling wastes can greatly affect project costs. The different drilling methods can also require vastly different volumes of groundwater be removed to fully develop the well.

5.4 CLIENT PREFERENCES

Certain clients have valid concerns regarding dust, noise, size, weight, or other nuisances related to drilling operations. For example, certain drilling methods require continuous operations until the borehole/well is completed, requiring lights for night work. This may not be possible in some situations. These site-specific or client-specific preferences must be considered when selecting a drilling method.

6.0 REFERENCES

Aller, L., T.W. Bennett, G. Hackett, R.J. Petty, J.H. Lehr, H. Sedoris, and D.M. Nielsen, 1989. Handbook of suggested practices for the design and installation of ground-water monitoring wells; National Water Well Association, Dublin, Ohio, 397 pp.

Driscoll, F.G., 1987. Groundwater and wells; Johnson Division; St. Paul, Minnesota, 1089 pp.

Nielsen, D. ed., 1991. Ground-water monitoring; Lewis Publishers, Chelsea, Michigan, 717 pp.

MWH
STANDARD OPERATING PROCEDURES

SOP-2
GROUNDWATER MONITORING WELL DESIGN AND INSTALLATION

MWH
MONTGOMERY WATSON HARZA

STANDARD OPERATING PROCEDURES

SOP-2
GROUNDWATER MONITORING WELL DESIGN AND INSTALLATION

TABLE OF CONTENTS

1.0 INTRODUCTION

This guideline is applicable to the design and installation of permanent monitoring wells at hazardous waste sites. Each monitoring well must be designed to suit the hydrogeologic setting, the type of contaminants to be monitored, the overall purpose of the monitoring program, and other site-specific variables. As such, site-specific objectives for each monitoring well and its respective intended use must be clearly defined before the monitoring system is designed. Additionally, within a monitoring system, different monitoring wells may serve different purposes and thus require different types of construction. Therefore, during all phases of well design, attention must be given to clear documentation of the basis for design decisions, the details of well construction, and the materials to be used. At many sites, precedence has been set as to well slot size and filter pack materials; therefore, it is not necessary to do a sieve analysis for determining well design details.

2.0 DEFINITIONS

Absorption	The penetration or apparent disappearance of molecules or ions of one or more substances into the interior of a solid or liquid.
Adsorption	The process by which atoms, ions, or molecules are assimilated to the surface of a material. Ion-exchange processes involve adsorption.
Annular Sealant	Material used to provide a positive seal between the borehole and the casing of the well. Annular sealants should be impermeable and resistant to chemical or physical deterioration.
Annular Space	The space between the borehole wall and the well casing, or the space between a casing pipe and a liner pipe.
Aquifer	A geologic formation, group of formations, or part of a formation that can yield water to a well or a spring.
Backwashing	A method of filter pack emplacement whereby the filter pack material is allowed to fall freely through the annulus while clean fresh water is simultaneously pumped down the casing.

Bentonite	Hydrous sodium montmorillinite mineral available in powder, granular, or pellet form. It is used to provide a tight seal between the well casing and the borehole.
Bridging	The development of gaps or obstructions in either grout or filter pack materials during emplacement.
Continuous Slot Wire-Wound Well Screen	A well intake that is made by winding and welding triangular-shaped, cold-rolled wire around a cylindrical array of rods. The spacing of each successive turn of wire determines the slot size of the intake.
Corrosion	The adverse chemical alteration that reverts elemental metals back to more stable mineral compounds and that affects the physical and chemical properties of the metal.
Filter Pack	Sand, gravel, or glass beads that are uniform, clean, and well-rounded that are placed in the annulus of the well between the borehole wall and the well intake to prevent formation material from entering through the well intake and to stabilize the adjacent formation.
Grout	A fluid mixture of neat cement and water with various additives or bentonite of a consistency that can be forced through a pipe and placed in the annular space between the borehole and the casing to form an impermeable seal.
Monitoring Well	A well that is capable of providing a groundwater level and sample representative of the zone being monitored.
Naturally Developed Well	A well construction technique whereby the natural formation materials are allowed to collapse around the well intake and fine formation materials are removed using standard development techniques.
Neat Cement	A mixture of Portland cement and water in the proportion of 5 to 6 gallons of clean water per bag (94 pounds) of cement.
Piezometers	A small-diameter, non-pumping well used to measure the elevation of the water table or potentiometric surface.

Sieve Analysis	Determination of the particle-size distribution of soil, sediment, or rock by measuring the percentage of the particles that will pass through standard sieves of various sizes.
Slurry	A thin mixture of liquid, especially water, and any of several finely divided substances such as cement or clay particles.
Tremie Pipe	A device, usually a small-diameter pipe, that carries grouting materials to the bottom of the borehole and that allows pressure grouting from the bottom up without introduction of appreciable air pockets.
Well Cluster	Two or more wells completed (screened) to different depths in a single borehole or in a series of boreholes in close proximity to each other. From these wells, water samples that are representative of different horizons within one or more aquifers can be collected.
Well Point	A sturdy, reinforced well screen or intake that can be installed by being driven into the ground.

3.0 RESPONSIBILITIES

The **Project Manager** selects the site-specific monitoring well design and installation methods, with input from the site hydrogeologist and field team leader, and oversees and prepares subcontracts.

The **Site Hydrogeologist** selects site-specific drilling/sampling options and helps prepare technical provisions of drilling subcontracts.

The **Field Team Leader** implements the selected drilling program.

The **Drilling Rig Geologist** supervises and/or performs actual monitoring well installation.

4.0 WELL DESIGN

Consideration should be given to the following site-specific information before a groundwater monitoring system is designed:

- Purpose of the groundwater monitoring program (water quality, water levels, remediation, flow direction, and velocities)

- Surficial conditions, including topography, climate, drainage, site access

- Known or anticipated hydrogeologic setting including geology (consolidated/ unconsolidated), physical characteristics of the aquifer (porosity/permeability), type of aquifer (confined/unconfined), recharge/discharge conditions, aquifer thickness, and groundwater/surface water interrelationships

- Borehole geophysical logs, if any

- Known or anticipated contaminant chemical characteristics (chemistry, density, viscosity, reactivity, and concentration)

- Anticipated seasonal fluctuations in groundwater levels

- Anthropogenic or tidal influences

- Regulatory requirements

Common mistakes in groundwater monitoring system design include the following:

- Use of well casing or well screen materials that are incompatible with the hydrogeologic environment, and/or the anticipated contaminants, resulting in chemical alteration of the samples or failure of the well

- Use of nonstandard well screen (field slotted or perforated) or incorrect slot size, resulting in well sedimentation and turbid groundwater samples

- Improper length or placement of the well screen so that acquisition of accurate water level or water quality data from discrete zones is impossible

- Improper selection and placement of filter pack materials resulting in well sedimentation, well screen plugging, or chemical alteration of the groundwater

- Improper selection and placement of annular seal materials resulting in alteration of groundwater chemistry, plugging of the filter pack and/or well screen, or cross-contamination from geologic units that have been sealed off improperly

- Inadequate surface protection resulting in surface water entering the well

Siting of monitoring wells should be performed after a preliminary estimation of the hydraulic gradients and groundwater flow direction. In most cases this may be done through review of background data and site terrain. Additionally, production wells in the area may be used to assess the local groundwater flow direction. If the groundwater flow direction cannot be determined by any of these methods, it may be practical to install piezometers in a preliminary phase to determine flow direction.

4.1 CASING DIAMETER AND SCREEN LENGTH

Monitoring well casing diameter is dependent on the purpose of the well and the amount and size of downhole equipment that must be accommodated. Additional criteria for selecting casing diameters include: drilling or well installation method used, anticipated depth of the well and associated strength requirements, ease of well development, volume of water required to be purged prior to sampling, rate of recovery of the well after purging, and cost.

Monitoring well casing diameters are generally 2 or 4 inches. Pumping tests or some types of borehole geophysical equipment may require wells 6 inches or larger in diameter. Four-inch-diameter wells are usually preferred due to their versatility. In smaller diameter wells, the volume of stagnant water to be purged prior to sampling is minimized, the cost of well construction is reduced, and the well stabilizes relatively quickly. The quantities of potentially contaminated drill cuttings and development and purge water are also reduced.

The borehole diameter should be a minimum of 4 to 6 inches larger than the well casing and screen to allow for proper placement of annular materials.

In situations where vertical groundwater gradients are minimal, screen lengths are typically 10 to 20 feet, with stratified formations possibly requiring shorter screen lengths. If non-aqueous phase liquids (NAPLs) that are lighter than water are anticipated, the well screen should extend above the water table so these liquids can be sampled. Consideration should be given to seasonal fluctuations in water levels when locating the well screen above the top of the water table. If dense NAPLs are anticipated, the screen interval should extend to the base of the aquifer. Well clusters may be necessary when contaminants both denser and lighter than water are anticipated in the same aquifer.

4.2 CASING AND SCREEN MATERIALS

Monitoring well casing is specified by diameter, thickness, and type of material. Well screens also require that slot size be specified. Casing thickness is referred to as "schedule." Polyvinyl chloride (PVC) is usually Schedule 40 (thinner wall), although Schedule 80 (thicker wall) is sometimes used for deep wells. Steel casing is typically Schedule 5 or 10.

Selection of casing and screen material must be based on three primary characteristics: chemical interference potential, chemical resistance, and physical strength. The materials must not assimilate chemicals either by adsorption onto the material surface or absorption into the material matrix or pores; they must be durable enough to withstand potential chemical attacks either from natural chemical constituents or groundwater contaminants; and they must have the structural strength to withstand the forces exerted on them by the surrounding geologic materials and during installation. The three components of casing and screen structural strength are tensile strength, compressive (column) strength, and collapse strength.

Casing and screen materials generally available are Teflon, PVC, stainless steel, galvanized steel, carbon steel, and low-carbon steel. Teflon materials are extremely expensive and of comparatively low strength. Although relatively inert, recent studies have shown that Teflon is prone to sorption of selected organic compounds.

The two most commonly used materials are PVC and stainless steel. PVC is inexpensive, widely available, lightweight, and easy to work with. Many studies have been conducted concerning the effect of PVC on water quality data. Whereas adsorption of some chlorinated species to PVC was documented, the adsorption rate was found to be very slow. Because a sample is generally taken shortly after the purging of stagnant water in contact with the casing, the contaminants in the water will have minimal time to be influenced by sorption or leaching effects. Therefore, potential sample bias effects due to interactions with PVC appear to be negligible. The column strength of PVC may limit the depth of installation. Schedule 80 PVC may be used for deeper wells; however, the reduced inside diameter should be taken into account when designing the well.

Steel well materials are stronger, more rigid, and less temperature sensitive than PVC or Teflon. Stainless steel has the highest corrosion resistance of the various types of steel. Type 304 and Type 316 are the most commonly used stainless steels. Both are available in low-carbon forms, which are more easily welded than the normal carbon steel. Low-carbon steel is designated by an "L" after the number (e.g., Type 304L). Type 304 stainless steel is superior to Type 316 from a corrosion resistance and cost standpoint. Type 316 is preferred to Type 304 under reducing conditions. For either type of stainless steel, long-term exposure to corrosive conditions may result in chromium or nickel contamination of groundwater samples. Insoluble halogen and sulfur compounds may also form as a result of corrosion of stainless steel.

Threaded, flush-joint casing is preferred for monitoring well applications. Welded-joint steel casing may also be acceptable, but is typically more expensive and inconvenient. Glued PVC should never be used for monitoring wells since the glue may release organic contamination into the well. The casing should have a well cap that is vented to prevent the accumulation of gases and to allow water levels in the well to respond to barometric and hydraulic pressure changes.

The hydraulic efficiency of a well screen depends primarily upon the amount of open area available per unit length of screen. The two screen types commonly used for monitoring wells are machine-slotted, and continuous-slot wire-wound. Hand-slotted, drilled, or perforated casings should not be used as well screens. Slotted casing is manufactured from a variety of materials, including PVC and stainless steel.

Slot openings are designated by numbers that correspond to the widths of the openings in thousandths of an inch (e.g., number 10 slot refers to 0.010-inch slot size). The slots have a consistent width for the entire wall thickness of the casing, which can result in clogging if irregularly shaped formation particles are brought through the screen during well development and sampling.

The continuous-slot, wire-wound screen has a greater area per opening per length and diameter than is available with any other screen type. The percentage of open area in continuous-slot screen is often more than twice that provided by standard slotted well screen. The triangular shaped wire makes these screens nonclogging. They are fabricated in PVC and a variety of metals and are used when high pumping rates are anticipated.

If a monitoring well will also be used for hydraulic testing, the well screen open area should equal or exceed the formation's effective porosity so that the screen is not the limiting factor in formation hydraulic testing. In most cases, this amount of open area can only be achieved through the use of continuous-slot wire-wound well screen. In choosing between types of well screens, another factor is the speed and effectiveness of well development. Screens with a high percentage of open area greatly reduce the time and effort required for well development.

The bottom of the screen must be sealed by an endcap consisting of the same material as the screen. The use of a sediment sump or trap below the well screen is not appropriate for monitoring wells.

4.3 DECONTAMINATION OF CASING AND SCREEN MATERIALS

During the production of PVC casing, a wax layer can develop on the inner wall of the casing; protective coatings may also be added to enhance casing durability. Considerable quantities of oils and solvents are used during the manufacturing and machining of threads during the production of steel casing. All of these represent potential sources of chemical interference and must be removed either with a laboratory-grade nonphosphate solution or by steam cleaning prior to installation. Factory cleaning of casing and screen in a controlled environment by standard detergent washing, rinsing, and air-drying procedures is superior to any cleaning efforts attempted in the field. Factory cleaned and sealed casing and screen can be certified by the supplier.

4.4 FILTER PACK AND WELL SCREEN DESIGN

A properly designed monitoring well requires that a well screen be placed opposite the zone to be monitored and be surrounded by materials that are coarser and of greater hydraulic conductivity than the natural formation material. Naturally developed wells and wells with artificially introduced filter pack are the two basic types of well intake designs for unconsolidated or poorly consolidated materials.

4.4.1 Naturally Developed Wells

In naturally developed wells, the formation materials are allowed to collapse around the well screen. Naturally developed wells can be installed in which natural formation materials are relatively coarse grained, permeable, and of uniform grain size. It is essential that the grain-size distribution of the formation to be monitored is accurately determined by conducting a mechanical (sieve) analysis of samples taken from the interval to be screened. After sieving, a plot of grain size versus cumulative percentage of sample retained on each sieve is made. Well screen slot sizes are based on the grain-size distribution, specifically the effective size (the sieve size that retains 90 percent of the formation material, referred to as D10) and the uniformity coefficient (the ratio of the sieve size that retains 40 percent of the material or D60, to the effective size). A naturally developed well can be justified if the effective grain size is greater than 0.010 inch and the uniformity coefficient is greater than 3.0. The California Department of Toxic Substances Control (DTSC) recommends that an artificial filter pack be used if sieve analysis indicates that a screen slot size of 0.020 inches or less is required to retain 50 percent of the natural formation. The biggest drawback for naturally developed wells is the time required for well development to remove fine-grained formation material.

4.4.2 Artificially Filter-Packed Wells

Filter packs are installed to create a permeable envelope around the well screen. The use of an artificial filter pack in a fine-grained formation material allows the screen slot size to be considerably larger than if the screen were placed in the formation material without the filter pack. The selection of the filter pack grain size should be based on the grain size of the finest layer to be screened.

Filter pack grain size and well screen slot size should be determined by the grain size distribution of the formation material. The filter pack should be designed first. It is recommended to use a filter pack grain size that is three to five times the average (D50) size of the formation materials. However, this method may be misleading in coarse, well-graded formation materials. Another way to determine filter pack grain size is to take the D30 grain size of the formation materials and multiplying it by a factor of between 3 and 6, with 3 used if the formation is fine and uniform and 6 used if the formation is coarse and nonuniform. For both methods, the uniformity coefficient of the filter pack materials should be as close to 1.0 as possible (2.5 maximum) to minimize particle size segregation during filter pack installation.

The filter pack should extend from the bottom of the well screen to approximately 2 to 5 feet above the top of the screen to account for settlement of the pack material during development and to act as a buffer between the well screen and the annular seal. A secondary filter pack (transitions sand) is sometimes used to prevent annular grout seal materials from migrating into the primary filter pack. The secondary filter pack should extend at least 1 foot above the top of the primary filter pack. It should consist of a uniformly graded fine sand with 100% passing a No. 30 U.S. Standard sieve and less than 2% by weight passing the 200 sieve.

Filter pack thickness must be sufficient to surround the well screen but thin enough to minimize resistance to the flow of fine-grained formation material and water into the well during development. American Society of Testing and Materials (ASTM), Designation D 5092-90, recommends that a minimum of 2-inch thick filter pack between the borehole well and the well casing (ASTM, 1995).

The materials comprising the filter pack should be as chemically inert as possible. It should be comprised of clean quartz sand or glass beads. Filter pack materials usually come in 100-pound bags; these materials are washed, dried, and factory packaged.

The size of well intake openings can only be selected after the filter-pack grain size is specified. The slot size should be such that 90 percent to 100 percent of the filter-pack material is held back by the well screen.

The casing string should be installed in the center of the borehole. This will allow the filter-pack materials to evenly fill the annular space around the screen and ensure that annular seal materials fill the annular space evenly around the casing. If a hollow-stem auger or dual-tube rig is used, the auger or inner tube of the dual tube will adequately centralize the casing string. For other types of drilling, centralizers should be used to ensure the casing string is positioned in the center of the borehole. Centralizers are typically expandable stainless steel metal or plastic that attach to the outside of the casing and are adjustable along the length of the casing. Centralizers are generally attached at the bottom and immediately above the well screen and at 10- or 20-foot intervals along the casing to the surface.

Methods for filter pack emplacement include gravity (free-fall), tremie pipe, reverse circulation, and backwashing. The latter two techniques are not commonly used for monitoring well construction, since they require the introduction into the borehole of water from a surface source.

Gravity emplacement is only possible in relatively shallow wells with an annular space of more than 2 inches, where the potential occurrence of bridging is minimized. Bridging can result in the occurrence of large unfilled voids in the filter pack or the failure of filter pack materials to reach their intended depth. Gravity emplacement may also cause filter pack gradation. Additionally, formation materials from the borehole wall can become incorporated into the filter pack, potentially contaminating it.

With the tremie emplacement method, the filter pack is poured or slurried into the annular space adjacent to the well screen through a rigid pipe, usually 1.5 inches in diameter. Initially the pipe is positioned so that its end is at the bottom of the annulus. If the filter pack is being installed in a temporarily cased borehole (hollow-stem auger , dual-tube percussion, or air rotary casing hammer) the temporary casing is pulled to expose the screen as the filter-pack material builds up around the well screen. In unconsolidated formations the temporary casing should only be pulled out 1 to 2 feet at a time to prevent caving. In consolidated or well-cemented formations or in cohesive unconsolidated formations, the temporary casing may be raised well above the bottom of the borehole prior to filter pack emplacement. For deep wells and/or nonuniform filter pack materials, the filter pack may be pressure fed through a tremie pipe with a pump. Emplacement should be continuously monitored with a weighted measuring tape accurate to the nearest 0.1 foot to determine when the filter pack has reached the desired height. After reaching the desired height, the well should be surged for 10-15 minutes, then checked for settling. Add more filter pack as necessary. Record the volume of filter pack used and check against calculated volume of annular space. Most well designs also employ a "secondary" filter pack (transition sand) above the primary filter pack for purposes of reducing bentonite seal and grout migration into the primary filter pack. If applicable, care must be taken that the filter pack materials are not installed into a hydrostratigraphic unit above or below the specific zone that is targeted for monitoring.

4.5 ANNULAR SEAL

Proper annular seal formulation and placement results in the complete filling of the annular space and envelopes the entire length of the well casing to ensure that no vertical migration can occur within the borehole.

Annular seal materials may include bentonite, neat cement grout, or variations of both. Typically, a bentonite seal from 2 to 5 feet thick is emplaced immediately above the filter pack. The use of bentonite as a sealing material depends on its efficient hydration following emplacement. Expansion of bentonite in water can be on the order of 8 to 10 times the volume of dry bentonite. This expansion causes the bentonite to provide a tight seal between the casing and the adjacent formation and between the grout and filter pack. Bentonite is available as pellets, granules, chips, chunks, or powder. The dry bentonite should be less than one-fifth the width of the annular space between casing and borehole (American Society of Testing and Materials [ASTM], 1995). If the bentonite seal will be above the saturated zone, several gallons of clean water must be poured down the annulus to begin the hydration process. A minimum of 30 minutes should pass to allow for hydration before additional annular seal materials are placed above the bentonite. Bentonite pellets having a coating to slow the hydration process are not recommended as they have been found to contain chemicals that may impact water quality.

Powdered bentonite is generally made into a grout slurry to allow emplacement as a bentonite seal. This grout slurry is prepared by mixing about 15 pounds of a high-solids, low-viscosity bentonite with 7 gallons of water to yield one cubic foot of grout. Once the grout is mixed, it should remain workable for 15 to 30 minutes. During this time the grout is pumped through a tremie pipe with a mud or grout pump. Once in place, the bentonite grout requires a minimum of 24 hours to strengthen. In water with a high total dissolved solids (TDS) content (>5000 ppm) or a high chloride content, the swelling of bentonite is inhibited.

A neat cement is commonly used to seal the remainder of the annulus. Neat cement is made up of one 94-pound bag of Portland cement and 6 gallons of water. The water used to mix the neat cement should be clean with a TDS <500 ppm. Bentonite powder is often added to neat cement to improve workability and reduce slurry weight and density and to reduce grout shrinkage. The proportion of bentonite by volume should be 3 to 5 percent.

The cement-bentonite grout should be mechanically blended in an aboveground rigid container and pumped through a tremie pipe to within a few inches of the bottom of the space to be sealed. This allows the grout to displace groundwater and loose formation materials up the hole. The end of the tremie pipe should always remain in the grout without allowing air spaces. After emplacement, the tremie pipe should be removed immediately. The grout should be placed in one continuous mass before initial setting of the cement or before the mixture loses its fluidity.

Cement is a highly alkaline substance (pH from 10 to 12) and introduces the possibility of altering the chemistry of the water it contacts. Thinner slurries may infiltrate an unprotected filter pack. After a borehole annulus is filled with grout a sample of water may be obtained and the pH determined in the field. A pH reading of 12 or higher may indicate an invasion of cement grout into the well.

4.6 SURFACE COMPLETIONS

Two types of surface completions are common for groundwater monitoring wells: aboveground and flush-mounted. Aboveground completions are preferred wherever practical. The primary purpose of either type of completion is to prevent surface runoff from entering and infiltrating down the annulus of the well, and to protect the well from accidental damage or vandalism. The surface seal may be an extension of the annular seal installed above the filter pack, or a separate seal emplaced atop the annular seal.

For aboveground completions, a protective steel casing fitted with a locking cover is set into the uncured cement surface seal. Guard posts should be spaced around each well to afford additional protection. Consult state or county requirements for specific design details.

In a flush-to-ground surface completion, a water-tight monitoring well Christy box or its equivalent is set into the cement surface seal before it has cured. This type of completion is used in high-traffic areas. A low, gently sloping mound of cement will discourage surface runoff. A locking well cap must be used to secure the inner well casing.

5.0 REFERENCES

National Water Well Association (NWWA), 1989. *Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells*, NWWA, Dublin, Ohio, 398 pp.

Nielson, David M. (ed.), 1991. *Practical Handbook of Ground-Water Monitoring*, Lewis Publishers, Chelsea, Michigan, 717 pp.

American Standard , 1995. *Standard Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers*, Designation D 5092-90.

MWHA INDUSTRIAL GROUP AND FEDERAL GROUP STANDARD OPERATING PROCEDURES

SOP-3
GROUNDWATER MONITORING WELL DEVELOPMENT

MWH
MONTGOMERY WATSON HARZA

STANDARD OPERATING PROCEDURES

SOP-3
GROUNDWATER MONITORING WELL DEVELOPMENT

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ATTACHMENTS

1.0 INTRODUCTION

The goal of monitoring well development is to remove fines and drilling fluid residue from the gravel pack and the natural formation in the vicinity of the screened interval, thus assuring good communication between the aquifer and the well. Well development assures that a sample collected will be a true representative of the quality of water moving through the formation.

The well development process is composed of the following:

The application of sufficient energy in a monitoring well to create groundwater flow reversals (surging) in and out of the well and the gravel pack to release and draw fines into the well

Pumping or bailing to draw drilling fluids out of the borehole and adjacent natural formation, along with fines that have been surged into the well

2.0 DEFINITIONS

Fines	Silt, clay, fine sand.
Parameters	Groundwater variables (i.e., pH, specific conductivity, temperature, turbidity).
Annulus	The gap between the well and borehole where the sand, seal, and grout are installed.
Saturated Annulus	The portion of the annulus that is below the aquifer.
Drilling Fluid	Any fluid the driller may have added during the drilling of the borehole.
Purge Water	Any water removed from the well via bailing, pumping, or airlift.
Drawdown	Distance between the static water level and water level while the well is being pumped or bailed at a constant rate.

Bridge	A wedge or buildup of sand that occurs when the driller is pouring the sand pack around the screened interval, thus leaving a gap or "open zone" where the natural formation could possibly clog the screen.
Yield	The rate at which a well will produce water.

3.0 RESPONSIBILITIES

The **Project Manager** selects site-specific development methods with input from the Field Team Leader, and oversees and/or prepares subcontracts.

The **Field Team Leader** implements the selected development program and assists in the selection of development methods and preparation of subcontracts.

The **Field Technician** carries out the actual well development.

4.0 WELL DEVELOPMENT

4.1 GENERAL

The following general guidelines are applicable to well development regardless of method.

4.1.1 Decontamination

Every effort must be made to avoid outside contamination and the cross-contamination of monitoring wells. This can best be done by ensuring that all equipment to be introduced into a well is clean. The level of effort for decontamination is a site- and project-specific issue to be resolved individually for each project.

4.1.2 Documentation

A critical part of monitoring well development is recording significant details and events in either a field logbook or on a well development log (Attachment 1). It is important that the following details be documented.

- Well identification number
- Installation date
- Date and time of development
- Quantity of drilling fluid lost during well installation
- All PID readings
- Measured well depth (pre-development and post-development)
- Water level
- Height of water column
- Pumping rate and water level drawdown (if applicable)
- Recharge rate (poor, good, excellent)
- Periodic parameter readings
- Sample observations
- Type of equipment used
- Total amount of water removed
- Completion time

4.1.3 Calculating Purge Volume

The minimum number of gallons to be removed must be calculated before the development process begins.

Information needed to calculate purge volume:

- Total depth of well (TD)
- Measured static water level (WL)
- Screen length (SL)
- Well casing inner diameter (ID)
- Borehole Diameter (BD)
- Number of gallons of water used during well drilling/construction
- Number of feet of filter pack installed above the screen, if the standing water column (SWC) is longer then the screen length

To calculate one well volume:

- Calculate the standing water column (SWC). TD minus WL equals SWC.
- Use a well volume chart (Attachment 2) to find a multiplier in the volume per linear foot column that coincides with the well's ID.
- SWC times ID multiplier equals gallons of water in one well volume

To calculate one annulus volume (two options):

<u>Option 1</u> (if the SWC is shorter than the screen length):

- Portion of saturated annulus equals SWC
- Use a volume chart to find a multiplier in the volume per linear foot column that coincides with the well's BD
- BD multiplier minus ID multiplier equals annulus multiplier
- Feet of saturated annulus times annulus multiplier times 30% (assumed porosity) equals gallons of water in one annulus volume

<u>Option 2</u> (if the SWC is longer than the screen length):

- Portion of saturated annulus is equal to the screen length plus the number of feet of sand above the top of the screen
- Use a volume chart to find a multiplier in the volume per linear foot column that coincides with the well's BD
- BD multiplier minus ID multiplier equals annulus multiplier
- Feet of saturated annulus times annulus multiplier times 30% (assumed porosity) equals gallons of water in one annulus volume

To calculate the minimum gallons to be removed:

- Well volume plus annulus volume plus number of gallons lost during well drilling/construction equals one purge volume

Example for the Development of a 4-inch Well

The Well Construction Log notes that the borehole diameter is 10.25 inches, the screen is 15 feet long, and the driller used 75 gallons of water during well construction. Measured with a water level indicator, the static water level is 59.45 feet. Measured with a well tagger, the well depth is 71.21 feet.

Record in logbook, TD = 71.25 feet
WL = 59.45 feet

TD minus WL = SWC
Logbook, SWC = 11.8 feet

From Chart 1 (Attachment 2), the gallons per linear foot multiplier for a 4-inch well is 0.66. Thus, 11.8 times 0.66 equals 7.79 (gallons of water in one well volume).

Logbook, one well volume = 7.79 gal.

From Chart 2 (Attachment 2), the gallons per linear foot for a 10.25-inch borehole is 4.29. Therefore, 4.937 (BD multiplier) minus 0.66 (ID multiplier) equals 3.63 (annulus multiplier). Thus, 11.8 times 3.63 times 30% equals 12.89 (gallons of water in one annulus volume).

Logbook, one annulus volume = 12.89 gal.
drilling fluid lost = 75 gal.

7.79 (one well volume) plus 12.89 (one annulus volume) plus 75 (fluid lost) equals 95.7 gallons (one purge volume). The work plan states that a minimum of three well volumes must be removed during development. Additional water may need to be purged to allow the parameters to stabilize and the water to clear up.

Logbook, one purge volume = 95.7 gal.
95.7 times 3 equals 287 (minimum number of gallons to be purged).
Logbook, minimum gallons to be purged = 287 gal.

4.2 DEVELOPMENT METHODS

4.2.1 Bailing, Surging, and Pumping

In relatively clean, permeable formations where water flows freely into the borehole, bailing, surging, and pumping is an effective development technique. The bottom of the well is first tagged to measure the amount of sand and silt before and after surging. Then a bailer (Figure 1) is lowered into the well to clean out any fines that have settled on the bottom. Then a surge block (Figure 2), approximately the same diameter as the well casing, is used to agitate the water, causing it to move in and out of the screen, which draws in fines from the gravel pack and surrounding formation, and breaks up any bridges that may have formed during the placement of the gravel pack. After surging for a few minutes (depending on the height of the water column and length of screen), the bailer is again lowered to clean out any fines that were drawn into the casing as a result of surging. This surge/bail technique should continue until minimal fines are being pulled out with the bailer. A submersible pump (Figure 3) is then be lowered down the well. Pumping should begin at the top of the saturated portion of the screened interval to prevent sand locking. The pump should be lowered at intervals of 5 feet or less until the pump is resting approximately 1 foot from the bottom of the casing. The water level must be monitored continuously during the first few minutes of pumping to prevent drawing the water level below the pump intake and breaking the suction. If possible, the discharge flow rate should be increased until the well is pumping at its maximum yield without a drawdown beneath the pump.

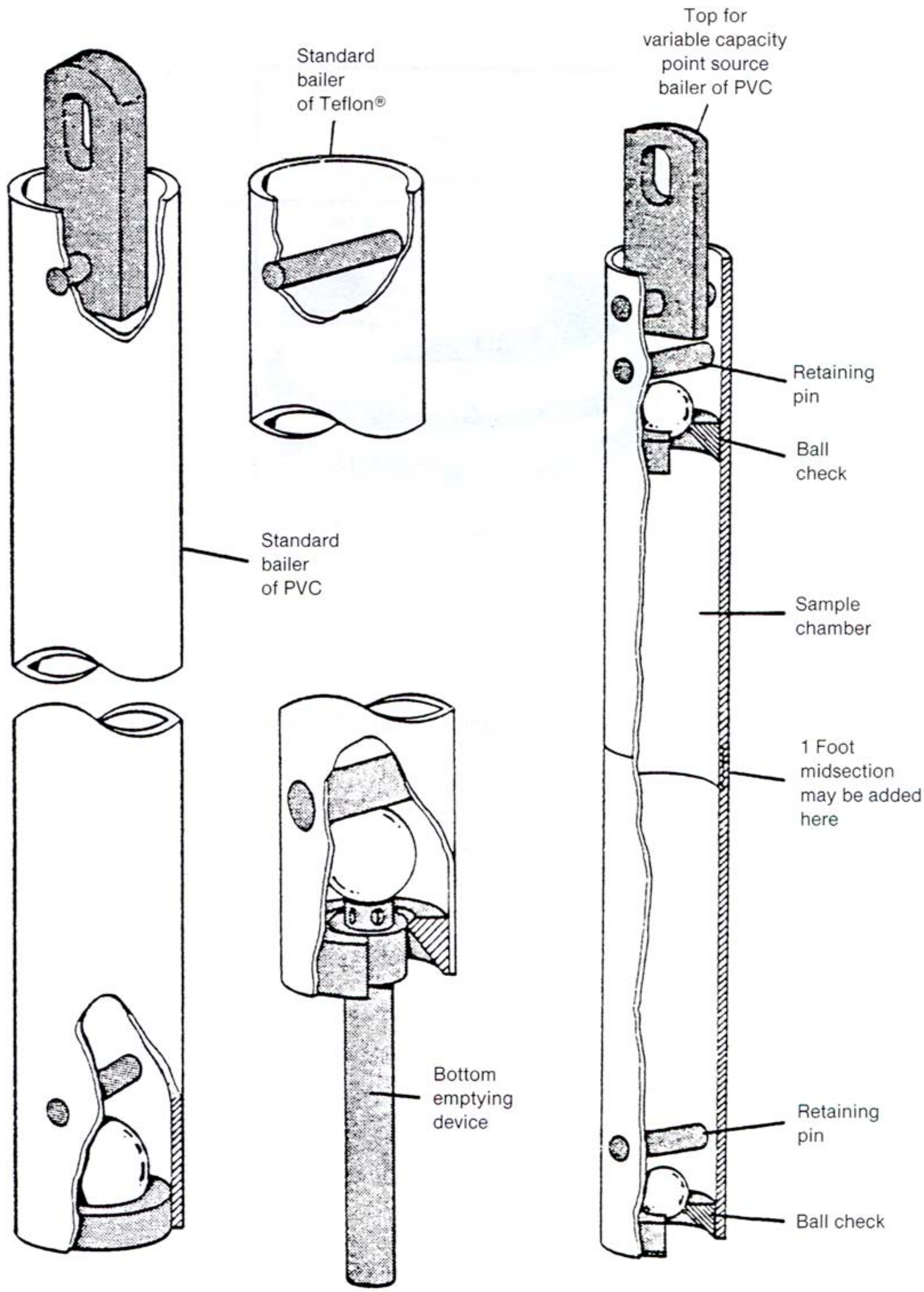


Figure 1 Bottom Discharge Bailer

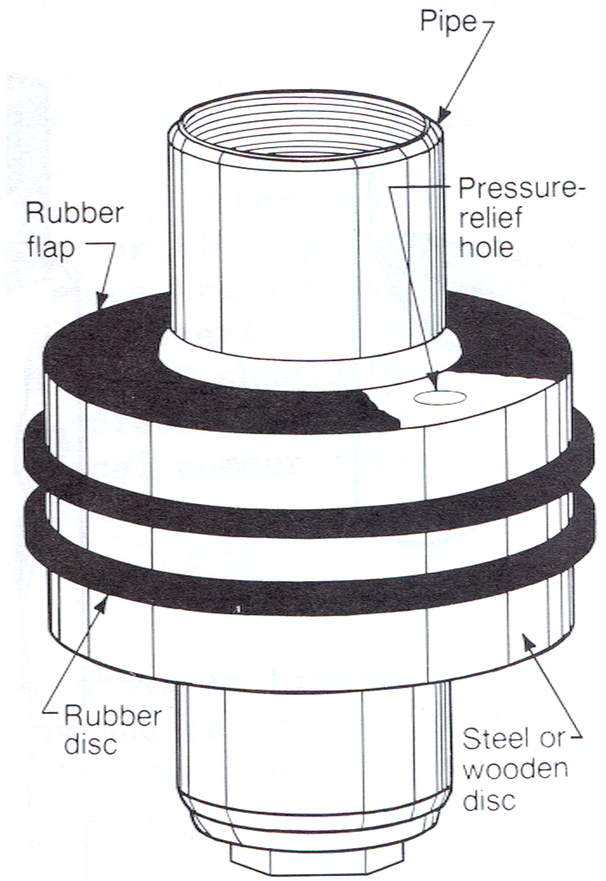


Figure 2 Surge Block

Figure 3 Submersible Pump

4.2.2 Overpumping and Backwashing

Wells may be developed by overpumping (pumping or bailing the well at a rate that exceeds the ability of the formation to deliver water) and then reversing the flow direction (backwashing) so that the water is passing from the well into the gravel pack and formation. This back and forth movement of water through the well screen and gravel pack removes fines from the formation immediately adjacent to the well, while preventing bridging (wedging) of sand grains. Backwashing can be accomplished by several methods including pouring water into the well and then bailing, or forcing water into the well under pressure through a water-tight fitting. Care should be taken when backwashing not to apply too much pressure, which could damage or destroy the well screen. Where no backflow prevention valve is installed, a pump can be alternately started and stopped. This starting and stopping allows the column of water that is initially picked up by the pump to be alternately dropped and raised in a surging action. This surge tends to loosen the bridging of the fine particles, drawing them into the well where they are pumped out.

4.2.3 Compressed Air

Compressed air can be used to develop a well by either backwashing or surging. Backwashing forces water out through the screens, using increasing air pressure inside a sealed well, then releases the pressurized air to allow the water to flow back into the well. Care should be taken when using this method so that the water level does not drop below the top of the screen, thus reducing well yield. Surging, or the "open well" method, consists of alternately releasing large volumes of air into an open well below the water level to produce a strong surge by virtue of the resistance of water head, friction, and inertia. The well is subsequently pumped using the air lift method.

4.2.4 Developing Wells with Floating Product

It is important to disturb the formation as little as possible in wells that contain floating product. Surge blocks should not be used as they may smear the screen and the casing when the block is being withdrawn, potentially leaving evidence of product and increasing the risk of faulty data. Product wells should be developed using a bail/pump method. A bailer should be lowered gently into the well, without agitating the water column, to remove any fines that have settled on the bottom. If the well produces sufficient water, a pump is lowered into the well and pumping started at a slow flow rate. The product/water level is manually monitored constantly for the first few minutes to prevent the product level from coming within 2 feet of the pump intake. Pumping is continued until at least the quantity of drilling fluid lost has been purged, the parameters have stabilized, and the discharge water is visibly clear.

4.2.5 Developing Wells in Tight Formations

Developing low-yield wells is a very lengthy process; the amount of time spent developing a low yield well is project-specific and should be resolved individually for each project. For wells installed in clay or fine-grained silt, the method of development should be bailing only. Surging of such wells has been found to substantially increase the turbidity of the water and does not significantly improve hydraulic well response. These wells should be bailed dry and a record kept of the time it takes for the well to recharge 80 percent.

5.0 REFERENCES

Aller, L., Bennett, T.W., Hackett, G., Petty, R.J., Lehr, J.H., Sedoris, H., and Nielsen, D.M., 1989. *Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells*; National Water Well Association, Dublin, Ohio, 228 pp.

Driscoll, F.G., 1987. *Groundwater and Wells*; Johnson Division; St. Paul, Minnesota, 497 pp.

Neilson, D. ed., 1991. *Ground-Water Monitoring*; Lewis Publishers, Chelsea, Michigan, 334 pp.

ATTACHMENT 1

WELL DEVELOPMENT LOG

ATTACHMENT 2

VOLUME CHARTS

MWH
MONTGOMERY WATSON HARZA

WELL DEVELOPMENT LOG

Well ID:	______	**Screened Interval (ft):**	______	**Well Diameter (in)**	______
Date:	______	**Pump Depth (ft):**	______	**Static Water Level (ft):**	______
Sample ID:	______	**Flow Rate (gpm)**	______	**Standing Water (ft):**	______
Time:	______	**Purging Device:**	______	**One Well Volume (gal):**	______
Method:	______	**Water Level Instrument:**	______	**OVA Reading at TOC:**	______
Technician:	______	**Water Quality Meter(s):**	______	**OVA Reading in BZ:**	______

Time	Volume Purged (gal)	Flow Rate (gpm)	Water Level (feet - TOC)	SC (µS/cm)	pH	Temp	ORP (mV)	Turbidity (NTU)	Other	Comments
			± 0.1 ft	5%	± 0.1	± 0.1 ºC	5%	< 10 NTU		
Final Field Parameter Measurements										

Comments: ______

Chart 1 — Volume of PVC Casing

Schedule	Diameter (inches)	OD (inches)	ID (inches)	Volume/LF (gallons)
40	1.25	1.660	1.380	0.08
40	2	2.375	2.067	0.17
40	3	3.500	3.068	0.38
40	4	4.500	4.026	0.66
40	6	6.625	6.065	1.50
40	8	8.625	7.981	2.60
40	12	12.750	11.938	5.82
80	2	2.375	1.939	0.15
80	4	4.500	3.826	0.60
80	5			0.00

Chart 2 — Volume of Open Borehold and Annulus Between Casing and Hole

Hole Diameter	Volume/Linear Feet of Hole		Nominal Casing Diameter	5.1.1.1 Volume/Linear Feet of Annulus	
(inches)	(gallons)	(cubic feet)	(inches)	(gallons)	(cubic feet)
7.25	2.14	0.29	1.3	2.08	0.28
7.25	2.14	0.29	2.0	1.98	0.26
7.75	2.45	0.33	2.0	2.29	0.31
8.25	2.78	0.37	2.0	2.61	0.35
10.25	4.29	0.57	2.0	4.12	0.55
8.25	2.78	0.37	3.0	2.41	0.32
10.25	4.29	0.57	3.0	3.92	0.52
12.25	6.12	0.82	3.0	5.76	0.77
8.25	2.78	0.37	4.0	2.12	0.28
10.25	4.29	0.57	4.0	3.63	0.49
12.25	6.12	0.82	4.0	5.47	0.73
12.25	6.12	0.82	6.0	4.65	0.62

MWH
STANDARD OPERATING PROCEDURES

SOP-5
WATER SAMPLING AND FIELD MEASUREMENTS

MWH
MONTGOMERY WATSON HARZA

STANDARD OPERATING PROCEDURES
SOP-5

WATER SAMPLING AND FIELD MEASUREMENTS

TABLE OF CONTENTS

1.0 INTRODUCTION

This guideline is a general reference for the proper equipment and techniques for groundwater sampling. The purpose of these procedures is to enable the user to collect representative and defensible groundwater samples and to facilitate planning of the field sampling effort. These techniques should be followed whenever applicable, although site-specific conditions or project-specific plans may require adjustments in methodology.

To be valid, a groundwater sample must be representative of the particular zone of the water being sampled. The physical, chemical, and bacteriological integrity of the sample must be maintained from the time of collection to the time of analysis in order to minimize changes in water quality parameters. Acceptable equipment for withdrawing samples from completed wells include bailers and various types of pumps. The primary considerations in obtaining a representative sample of the groundwater are to avoid collecting stagnant (standing) water in the well, to avoid physically or chemically altering the water due to improper sampling techniques, sample handling, or transport, and to document that proper sampling procedures have been followed.

This guideline describes suggested well evacuation methods, sample collection and handling, field measurement, decontamination, and documentation procedures. Examples of sampling and chain-of-custody (COC) forms are attached.

2.0 DEFINITIONS

<u>Annular Space</u>: The space between casing or well screen and the wall of the drilled hole, or between drill pipe and casing, or between two separate strings of casing. Also called annulus.

<u>Aquifer</u>: A geologic formation, group of formations, or part of a formation that is capable of yielding a significant amount of water to a well or spring.

<u>Bailer</u>: A long narrow tubular device with an open top and a check valve at the bottom that is used to remove water from a well during purging or sampling. Bailers may be made of Teflon,

polyvinyl chloride (PVC), or stainless steel. Disposable bailers are available and are made of polycarbonate.

Bladder Pump: A pump consisting of flexible bladder usually made of Teflon contained within a rigid cylindrical body (commonly made of PVC). The lower end of the bladder is connected through a check valve to the intake port, while the upper end is connected to a sampling line that leads to the ground surface. A second line, the gas line, leads from the ground surface to the annular space between the bladder and the outer body of the pump. After filling, under hydrostatic pressure, application of gas pressure causes the bladder to collapse, closing the check valve and forcing the sample to ground surface through the sample line. Gas pressure is often provided by a compressed air tank, and commercial models generally include a control box that automatically switches the gas pressure off and on at appropriate intervals.

Centrifugal Pump: A pump that moves a liquid by accelerating it radially outward in an impeller to a surrounding spiral-shaped casing.

Chain of Custody: Method for documenting the history and possession of a sample from the time of its collection through its analysis and data reporting to its final disposition.

Check Valve: Ball and spring valves on core barrels, bailers, and sampling devices that are used to allow water to flow in one direction only.

Conductivity (electrical): A measure of the quantity of electricity transferred across a unit area, per unit potential gradient, per unit time. It is the reciprocal of resistivity.

Datum: An arbitrary surface (or plane) used in the measurement of heads (i.e., National Geodetic Vertical Datum [NGVD], commonly referred to as mean sea level [msl]).

Decontamination: A variety of processes used to clean equipment that contacted formation material or groundwater that is known to be or suspected of being contaminated.

Downgradient: In the direction of decreasing hydrostatic head.

Drawdown: The lowering of the potentiometric or piezometric surface in a well and aquifer due to the discharge of water from the well.

Electric Submersible Pump: A pump that consists of a rotor contained within a chamber and driven by an electric motor. The entire device is lowered into the well with the electrical cable and discharge tubing attached. A portable power source and control box remain at the surface. Electrical submersible pumps used for groundwater sampling are constructed of inert materials such as stainless steel, and are well sealed to prevent sample contamination by lubricants.

Filter Pack: Sand or gravel that is generally uniform, clean, and well rounded that is placed in the annulus of the well between the borehole wall and the well screen to prevent formation material from entering through the well screen and to stabilize the adjacent formation.

Headspace: The empty volume in a sample container between the water level and the cap.

HydroPunch®: An in situ groundwater sampling system in which a hollow steel rod is driven into the saturated zone and a groundwater sample is collected.

In Situ: In the natural or original position; in place.

Monitoring Well: A well that is constructed by one of a variety of techniques for the purpose of extracting groundwater for physical, chemical, or biological testing, or for measuring water levels.

Packer: A transient or dedicated device placed in a well or borehole that isolates or seals a portion of the well, well annulus, or borehole at a specific level.

Peristaltic Pump: A low-volume suction pump. The compression of a flexible tube by a rotor results in the development of suction.

pH: A measure of the acidity or alkalinity of a solution, numerically equal to 7 for neutral solutions, increasing with increasing alkalinity and decreasing with increasing acidity. (Original designation for potential of hydrogen.)

Piezometer: An instrument used to measure head at a point in the subsurface; a nonpumping well, generally of small diameter, that is used to measure the elevation of the water table or potentiometric surface.

Preservative: An additive (usually an acid or a base) used to protect a sample against decay or spoilage, or to extend the holding time for a sample.

Static Water Level: The elevation of the top of a column of water in a monitoring well or piezometer that is not influenced by pumping or conditions related to well installation, hydrologic testing, or nearby pumpage.

Turbidity: Cloudiness in water due to suspended and colloidal organic and inorganic material.

Upgradient: In the direction of increasing static head.

3.0 RESPONSIBILITIES

Project Manager: Selects site-specific water sampling methods, locations for monitoring well installations, monitoring wells to be sampled and analytes to be analyzed with input from the field team leader (FTL) and project geologist. Responsible for project quality control and field audits.

Field Team Leader: Implements water sampling program. Supervises project geologist/hydrogeologist and sampling technician. Insures that proper chain-of-custody procedures are observed and that samples are sampled, transported, packaged, and shipped in a correct and timely manner.

Project Geologist/Hydrogeologist: Insures proper collection, documentation, and storage of groundwater samples prior to shipment to the laboratory. Assists in packaging and shipment of samples.

Field Sampling Technician: Assists the project geologist/hydrogeologist in the completion of tasks and is responsible for the proper use, decontamination, and maintenance of groundwater sampling equipment.

4.0 WATER SAMPLING GUIDELINES

4.1 WELL EVACUATION AND SAMPLING EQUIPMENT

There are many methods available for well purging. A variety of issues must be considered when choosing evacuation and sample collection equipment including: the depth and diameter of the well, the recharge capacity of the well, and the analytical parameters that will be tested. Few sampling devices are suitable for the complete range of groundwater parameters. For example, an open bailer is acceptable for collecting major ion and trace metal samples, but it may lead to erroneous analytical results if used for the collection of samples that are analyzed for volatile organics, dissolved gases, or even pH. Generally, the best pumps to use are positive displacement pumps, such as bladder and helical rotor pumps that minimize the aeration of the groundwater as it is sampled, and therefore yield the most representative groundwater samples. Although it is possible to use different equipment to evacuate the well and to sample the well, this is not recommended because of the increased decontamination requirements and possibilities for cross contamination. It is recommended that a flow rate as close to the actual groundwater flow rate should be employed to avoid further development, well damage, or the disturbance of accumulated corrosion or reaction products in the well (Puls and Barcelona, 1989).

Positive displacement pumps, such as bladder pumps, are generally recommended for both well evacuation and sample collection. Other types of sample collection, such as bailing or the use of gas lift pumps, should be avoided, especially when analyzing for sensitive parameters because of the geochemical changes that can occur due to the aeration of the water within the well. Also, the use of these sample devices may entrain suspended materials, such as fine clays and colloids which are not representative of mobile chemical constituents in the formation of interest (Puls and Barcelona, 1989).

Specific instructions for the use of several of the sampling devices are discussed in the next sections. All purging and sampling equipment should be decontaminated before beginning work and between wells in accordance with Section 4.4.

Bailers. Bailers represent the simplest and least expensive method of collecting the sample from a well. However, they may not be suitable for all analyses. For most applications, the bailer should be constructed of Teflon or stainless steel. Disposable bailers constructed of polyethylene may also be acceptable for some applications (e.g., sampling for petroleum hydrocarbons), and they represent a simple method of avoiding cross-contamination between samples without the time-consuming need for decontamination. The following issues should be considered when using bailers for sampling:

- Bailers should be decontaminated per Section 4.4 of these guidelines and then isolated from any type of contamination prior to use for purging or sampling. The bailer should be decontaminated prior to the first well and between each subsequent well.

- Stainless steel or Teflon-coated stainless steel wire is recommended for lowering and retrieving the bailer from the well. At no time should the bailer or the line touch the ground during the sampling process. This can be done by coiling the line in a bucket or on a sheet of polyethylene. Polypropylene line may be substituted for the stainless steel wire, but should be discarded after each use.

- When lowering the bailer into the well, care should be taken to minimize agitation in the well, such as when the bailer contacts the water-table surface.

Peristaltic/Centrifugal Pumps. Peristaltic and centrifugal pumps are widely used for purging of wells with water levels close to the surface (less than 30 feet). They are reasonably portable, light, and easily adaptable to ground-level monitoring of field parameters by attaching a flow-through cell. These pumps require minimal downhole equipment, and they can easily be cleaned in the field, or the entire tubing assembly can be changed for each well. The following procedures should be considered when using these pumps:

- Prior to use, the exterior and interior of all intake tubing for use with the peristaltic/centrifugal pump should be thoroughly flushed with tap water and then double rinsed with distilled water. New tubing should be used at each well and then discarded. If a gas-powered generator is used, it should be downwind of the well.

- The intake of the suction tubing should be lowered to the midpoint of the well screen. Alternatives to this procedure may be necessary if the drawdown from the purging operations causes the water level to fall and begin to pump air. The suction line should be lowered slowly into the well until it pumps water continuously but not lower than 1 foot above the bottom of the well.

- If parameters are to be monitored continuously, connect the instrumentation header to the pump discharge and begin flushing the well. Continuously monitor the parameters (pH, Eh, temperature, and specific conductivity) and measure the volume of groundwater being pumped. Alternately, parameters may be monitored in a beaker filled from the pump discharge.

- After purging, remove the intake tubing from the well while the pump is still pumping to prevent backwash of water into the well. Stop the pump and disconnect the tubing from the pump for cleaning or disposal.

- If tubing is to be reused (not recommended), clean the interior of the tubing by flushing thoroughly with tap water. Double rinse the tubing with distilled water. Using Alconox and water, wash the exterior of the tubing, and then rinse with tap water and distilled water.

Gas-Lift Pumps. A pressure displacement system consists of a chamber equipped with a gas inlet line, a water discharge line and two check valves. When the chamber is lowered into the casing, water floods it from the bottom through the check valve. Once full, a gas (e.g., nitrogen or air) is forced into the top of the chamber in sufficient amounts to displace the water out the discharge tube. The check valve in the bottom prevents water from being forced back into the casing, and the upper check valve prevents water from flowing back into the chamber when the gas pressure is released. This cycle can be repeated as necessary until purging is complete. The pressure lift system is particularly useful when the well depth is beyond the capability of a peristaltic or centrifugal pump. The water is displaced up the discharge tube by the increased gas pressure above the water level. The potential for increased gas diffusion into the water makes this system unsuitable for sampling volatile organic or most pH critical parameters. The entire pump assembly and tubing should be decontaminated before beginning purging and between wells as described in Section 4.4. The following procedures should be considered when using these pumps:

- Determine depth to midpoint of screen or depth to well section open to the aquifer (consult driller's or well completion log).
- Lower displacement chamber until top is just below water level.
- Attach gas supply line to pressure adjustment valve on cap.
- Gradually increase gas pressure to maintain discharge flow rate.
- Measure rate of discharge frequently. A bucket and stopwatch are usually sufficient.
- Purge a minimum of five casing volumes or until discharge characteristics stabilize (see discussion on well purging).

Submersible Pumps. Submersible pumps take in water and push the sample up a sample tube to the surface. The power sources for these pumps may be compressed gas or electricity. The operation principles vary, and the displacement of the sample can be by an inflatable bladder, sliding piston, gas bubble, or impeller. Bladder or helical rotor pumps are recommended for sampling for sensitive parameters. Pumps are available for 2-inch-diameter wells and larger, and these pumps can lift water up to several hundred feet. The entire pump assembly and tubing should be decontaminated before beginning purging and between wells as described in Section 4.4.

Limitations of this class of pumps include:

- They may have low delivery rates.
- Many models of these pumps are expensive.
- Compressed gas or electricity is needed.
- Sediment in water may cause clogging of the valves or eroding the impellers with some of these pumps.
- Decontamination of internal components of some types is difficult and time consuming.

Advantages of this class of pumps include:

- Delivery of low turbidity samples.
- Adjustable to very low flow rates.
- Some types (e.g., bladder pumps) are relatively inexpensive and easy to install as dedicated systems.
- Some types (e.g., bladder pumps) can be easily disassembled for decontamination.

HydroPunch® Groundwater Sampling System. The HydroPunch® provides in situ groundwater samples by using a specially designed sample tool to provide a hydraulic connection with the adjacent water table. Both groundwater and floating layer hydrocarbons may be sampled using the HydroPunch®. These are two types of HydroPunch® available for use today: HydroPunch I and HydroPunch II. The main difference between the original system (HydroPunch I) and the HydroPunch II is in the amount of groundwater that can be extracted from the formation using each of the methods. The HydroPunch I allows for only one sample of very low volume to be collected while the HydroPunch II allows for the withdrawal of as much groundwater as is required for the analyses being conducted.

In the HydroPunch I Groundwater Sampling System, the sample tool is pushed to the proper zone (at least 5 feet of submergence for groundwater sampling) and then withdrawn to expose an inlet screen. The interior of the sample tool fills with water. When the HydroPunch® is recovered, check valves keep the sample from draining. Discharge to sample containers is accomplished through a stopcock.

The HydroPunch II utilizes the same type of system to collect groundwater samples except this sampler is lowered and pushed into the groundwater on hollow push rods. A 1-inch-diameter stainless steel bailer is then lowered down the hollow push rods and into the exposed screened interval of the HydroPunch II. The bailer can be lowered to the water table as many times as are required to obtain a sufficient volume of water for analyses.

Both systems may be pushed through as much as 60 feet of soft sediments to collect groundwater samples. In coarse sand, gravel, consolidated rock, or at depths greater than 60 feet, a pilot hole must be drilled prior to driving the HydroPunch® into the saturated zone.

Advantages of this system include low cost, the ability to collect a relatively undisturbed in situ groundwater sample, and the relative speed with which a sample can be collected when compared to drilling, installing, developing, purging, and sampling a monitoring well. Disadvantages are that an accurate water level can not be obtained using the HydroPunch®, sampling cannot be repeated if problems occur with the samples after they are collected, and it does not allow for long-term groundwater monitoring.

The HydroPunch® is ideal for screening for contaminants or defining a contaminant plume when resources are not available to install a large number of monitoring wells.

4.2 WELL EVACUATION METHODS

4.2.1 Purging Requirements

To obtain a representative groundwater sample it must be understood that the composition of the water within the well casing and in close proximity to the well is probably not representative of the overall groundwater quality in the target aquifer. This is due to the possible presence of drilling materials near the well and because important environmental conditions such as the oxidation-reduction (redox) potential may differ drastically near the well from the conditions in the surrounding water-bearing materials. For these reasons it is necessary to pump or bail the well until it is thoroughly flushed of standing water and contains fresh water from the aquifer. The recommended amount of purging before sampling is dependent on many factors including the characteristics of the well, the hydrogeological nature of the aquifer, the type of sampling equipment being used, and the parameters that are to be analyzed.

The number of casing volumes that should be removed prior to sample collection has been a matter of debate in the groundwater community for some time. The consensus seems to be that rather than relying on the removal of a specific volume of water (such as five casing volumes) prior to sample collection, physical parameters such as pH, specific conductivity, temperature, and possibly redox potential should be used to evaluate when enough water has been removed from the well to obtain a representative groundwater sample. However, it is recommended that where possible, a minimum of five casing volumes should be purged prior to sampling. The sensitivity of the above parameters to changes as a result of exposure of groundwater to surface level conditions (i.e., changes in the partial pressure of dissolved gases or the conditions of the purging system) make in situ monitoring desirable. An alternative to this would be to conduct these measurements in a closed cell attached to the discharge side of the pump system. Puls and Barcelona (1989) suggest that an initial estimate for the time of pumping necessary to collect representative water from a formation is around two times the time required to get plateau values for the above parameters. For example, the parameters may be considered stable when several consecutive measurements (collected at least one-half a casing volume apart) do not change by more than the following:

- Conductivity ±10 percent
- pH ±0.4 units
- Temperature ±2˚C

When evacuating low yield wells (wells that are incapable of yielding at least five casing volumes), the well should be evacuated to dryness once (USEPA, 1986). As soon as the well recovers sufficiently, the samples should be collected and containerized in the order of the parameter volatilization sensitivity. The samples should be retested for field parameters after sampling as a check on the stability of the water samples over time. Whenever full recovery exceeds 2 hours, the sample should be collected as soon as sufficient volume is available for a sample for each parameter. However, allowing a well to recover overnight is not acceptable. At no time should the well be pumped to dryness if the recharge rate causes the formation water to vigorously cascade down the sides of the screen and cause an accelerated loss of volatiles. In this case, samples should be collected at a rate slow enough to maintain the water level at or above the top of the screen to prevent cascading.

Other factors that will influence the amount of purging required before sampling include the pumping rate and the placement of the pumping equipment within the column of water in the well. For example, recent studies have shown that if a pump is lowered immediately to the bottom of a well before pumping, it may take some time for the column of water above it to be exchanged if the transmissivity of the aquifer is high and the well screen is at the bottom of the casing. In these cases, the pump will be drawing water primarily from the aquifer. Purging from higher in the well or just below the water surface provides a more complete removal of the casing water.

4.2.2 Calculation of Casing Volume

To insure that an adequate volume of water has been removed from the well prior to sampling, it is first necessary to determine the volume of standing water in the well and the volume of water in the filter pack below the well seal. The volume can be easily calculated by the following method (calculations should be entered in the field logbook):

1. Obtain all available information on well construction (e.g., location, casing, screen, depth).

2. Determine well or casing diameter.

3. Measure and record static water level (depth below ground level or top of casing reference point) using one of the methods described in Section 2.3.1.

4. Determine depth of well by sounding using a clean, decontaminated weighted tape measure or an electronic water-level probe.

5. Calculate the volume of water in the casing using the following formula:

$$V = 7.481 (\_r2h)$$

where:

V = Casing Volume (gal)
r = Well radius (ft) = well diameter (ft)/2
h = Linear feet of water in well = total well depth (ft) - static water depth (ft)

Alternatively, the casing volume can be calculated by multiplying the linear feet of water in the well by the volume per linear feet taken from Attachment 1 or other similar tables. Always be sure that the units in your calculation are consistent. In the equation above, 7.481 is the conversion factor from cubic feet to gallons.

4.2.3 Calculation of Annulus Volume

Some groundwater sampling protocol require the evacuation of casing and annulus volumes prior to sampling. In these cases the volume of water contained in the annular space between the casing and the borehole wall is calculated by the following formula:

$$Vc = (Cb - Cc) \times (h) \times (0.30)$$

where:

Cb = Borehole Capacity (Volume in Gal./ft)
Cc = Casing Capacity (Volume in Gal./ft)
h = Amount of standing water in the well
0.30 = Average porosity of typical sand pack

The annulus volume is added to the casing volume prior to multiplying by the number of volumes to be excavated.

4.2.4 Purge Water Handling and Disposal

Because of the potential for spreading environmental contamination, planning for purge water disposal is a necessary part of well monitoring. Alternatives range from releasing it on the ground (not back down the well) to full containment, treatment, and disposal. If the well is believed to be contaminated, the best practice is to contain the purge water and store it in drums labeled "purge water" or in aboveground portable storage tanks (i.e., "Baker Tanks") until the water samples have been analyzed. Once the contaminants are identified, appropriate treatment or disposal requirements can be determined.

4.3 SAMPLE COLLECTION METHODS

All groundwater samples should be collected using a clean, dry decontaminated bailer made of either stainless steel or Teflon unless a HydroPunch® groundwater system is being used.

4.3.1 Sample Containers

A complete set of sample containers should be prepared by the laboratory prior to going into the field. The laboratory should provide the proper containers with the required preservatives. The laboratory's QA manual should provide a complete description of the procedures used to clean and prepare the containers. The containers should be labeled in the field with the date, well designation, project name, collectors' name, time of collection, and parameters to be analyzed. The sample containers should be kept in a cooler (at 4˚C) until they are needed (i.e., not left in the sun during purging). One cooler should be used to store the unfilled bottles and another to store the samples.

The sample bottles will be filled in order of the volatility of the analytes so that the containers for volatile organics will be filled first, and samples that are not pH-sensitive or subject to loss through volatilization will be collected last. A preferred collection order (as listed in USEPA, 1986) is as follows:

- Volatile organics (VOCs)

- Total petroleum hydrocarbons (TPH)
- Total organic halogens (TOX)
- Total organic carbon (TOC)
- Extractable organics (e.g., BNAs, pesticides, herbicides)
- Total metals
- Dissolved metals
- Phenols
- Cyanide
- Sulfate and chloride
- Turbidity
- Nitrate and ammonia
- Radionuclides

Temperature, pH, and specific conductance should be measured and recorded in the field before and after sample collection to check on the stability of the water samples over time.

4.3.2 Field Filtration for Dissolved Metals

Filtering groundwater samples has been a subject of considerable debate in recent years. In many cases, samples passing a 0.45 micron (μm) filter were used to provide an indication of dissolved metals concentrations in groundwater. Puls and Barcelona (1989) report that the use of a 0.45 micron filter was not useful, appropriate, or reproducible in providing information on metals mobility in groundwater systems, nor was it appropriate for determination of truly "dissolved" constituents in groundwater. A dual sampling approach is recommended to collect both filtered and unfiltered samples.

Any filtration for estimates of dissolved species loads should be performed in the field with no air contact and immediate preservation and storage. In-line pressure filtration is best with as small a filter pore size as practically possible (e.g., 0.45, 0.10 micron). Disposable, in-line filters are recommended for convenience and avoiding cross-contamination. The filters should be pre-rinsed with distilled water; work by Jay (1985) showed that virtually all filters require pre-washing to avoid sample contamination.

In the absence of filters, sample turbidity can generally be reduced by using bladder pumps. USEPA (1986) recommends that the turbidity should be less than 5 nephelometric turbidity units (NTUs).

4.3.3 Sampling from Non-Monitoring Wells and Springs/Seeps

Municipal/Private Wells. Domestic water supply wells should be sampled in a similar manner to monitoring wells, although allowances must be made for the type of pumping equipment already installed in the well. The sampling point should be determined at the time of sampling, and it should be the cold-water tap as close to the pump as practical. Domestic supply samples should not be taken from taps delivering chlorinated, aerated, softened, or filtered water. Faucet aerators should be removed if possible before sampling. The water tap should be turned on and run for at least 30 minutes unless the water tap is directly adjacent to the well head, and then the water should be allowed to run for no less than 10 minutes before the samples are collected to flush stagnant water from the system. Prior to collecting the sample, reduce the flow rate to approximately 50 milliliters per minute (ml/min). All sample containers should be filled with water directly from the tap and the samples processed as described for monitoring well samples. Components of the plumbing system should be noted to assist in data interpretation.

Groundwater should be collected from water supply wells in a manner as consistent with the monitoring well sampling procedure as the circumstances permit. In most cases, this will involve sampling directly from the tap on each well and before the water has gone through any chlorination or treatment system.

Spring and Seep Sampling. Samples from springs or seeps should be collected directly into the sample bottles without using any special sampling equipment. The sample will be collected as close as possible to where the spring emanates from the soil or rock. The sampler should always stand downstream of the spring or seep to avoid disturbing sediment or clouding the water.

4.4 FIELD MEASUREMENTS

A variety of field measurements are commonly made during the sampling of groundwater including: water level, pH, conductivity, and temperature. The accuracy, precision, and usefulness of these measurements is dependent on the proper use and care of the field instruments. Valid and useful data can only be collected if consistent practices (in accordance with recommended manufacturers instructions) are followed. The instruments should be handled carefully at the well site and during transportation to the field and between sampling sites.

4.4.1 Water Level

Water levels can be measured by several techniques, but the same steps should be followed in each case. The proper sequence is as follows:

1. Check operation of measurement equipment aboveground. Prior to opening the well, don personal protective equipment as required.

2. Record all information specified below on a sampling form or in the field notebook if a form is not available.

3. Record well number, top of casing elevation, and surface elevation if available.

4. Measure and record static water level and total depth to the nearest 0.01 foot (0.3 cm) from the surveyed reference mark on the top edge of the inner well casing. If no reference mark is present, record in the log book where the measurement was taken from (i.e., from the north side of the inner casing).

5. Record the time and day of the measurement.

6. Some water-level measuring devices have marked metal or plastic bands clamped at intervals along the measuring line used for reference points to obtain depth measurements. The spacing and accuracy of these bands should be checked before each round of measurements because they may loosen and slide up or down the line, resulting in inaccurate reference points.

Electric Water Level Indicators. These devices consist of a spool of small-diameter cable or tape and a weighted probe attached to the end. When the probe comes in contact with the water, an electrical circuit is closed and a meter, light, and/or buzzer attached to the spool will signal the contact. This is the recommended method for obtaining accurate water-level measurements.

There are a number of commercial electric sounders available, none of which is entirely reliable under all conditions likely to occur in a contaminated monitoring well. In conditions where there is oil on the water, groundwater with high specific conductance, water cascading into the well, or a turbulent water surface in the well, measuring with an electric sounder may be difficult.

For accurate readings, the probe should be lowered slowly into the well. The electric tape is marked at the measuring point where contact with the water surface was indicated. The distance from the mark to the nearest tape bank is measured using a ruler or steel tape and added to the band reading to obtain the depth to water. Band spacing should be checked periodically as described above.

Chalked Steel Tape. Water level is measured by chalking a weighted steel tape and lowering it a known distance (to any convenient whole-foot mark) into the well or borehole. The water level is determined by subtracting the wetted chalked mark from the total length lowered into the hole.

The tape should be withdrawn quickly from the well because water has a tendency to rise up the chalk due to capillary action. A paste called "National Water Finder" may be used in place of chalk. The paste is spread on the tape the same way as the chalk but the part that gets wet turns red. This paste is manufactured by the Metal Hose and Tubing Company, Dover, New Jersey.

Disadvantages to this method include: depths are limited by the inconvenience of using heavier weights to properly tension longer tape lengths (typically, 100 foot tapes require a 10- to 12-pound weight to tension adequately); it is ineffective if borehole/well wall is wet or inflow is occurring above the static water level; chalking the tape is time consuming; and it is difficult to use in the rain. The water chemistry may also be modified somewhat by the addition of chalk or paste.

4.4.2 pH

The pH meters should be calibrated against two standard pH solutions, either 4 and 7 or 7 and 10, depending on whether previous pH measurements have been less than or greater than 7, respectively. The meter readings will be adjusted, and the probe should then be rinsed thoroughly with distilled water. The probe should then be immersed in the water sample, and the pH and temperature recorded in the field log or on the sampling form. The manufacturer's directions for calibration, maintenance, and use should be read and closely followed. Any problems with the functioning of the meter should be noted in the field log and reported to the office equipment manager.

4.4.3 Conductivity

Specific conductivity meters should be standardized by immersing a decontaminated specific conductivity probe into a standard solution of conductivity buffer. The conductivity of the standard solution should be within the same order of magnitude as anticipated for the water sample. The meter reading will be adjusted to the buffer solution value, and the probe will then by thoroughly rinsed with distilled water. The probe should then be immersed in the well water sample, and the conductivity value recorded. The manufacturer's directions for calibration, maintenance, and use should be read and closely followed. Calibrant solutions should be dated and discarded on their expiration date. Any problems with the functioning of the meter should be noted in the field log and reported to the office equipment manager.

4.4.4 Temperature

Temperature measurements should be made with either a mercury or electronic thermometer capable of accurately reading to 0.1˚C. The temperature reading should be recorded in the field log or on the sampling form.

4.5 DECONTAMINATION

The general decontamination procedure for all non-dedicated groundwater sampling equipment (bailers, pumps, water-level probes) consists of the following steps:

1. Scrub and wash with laboratory-grade detergent (such as Alconox) and tap water;
2. Rinse with reagent-grade isopropanol alcohol or methanol and allow to air dry; and
3. Triple rinse with deionized water.

If available, a steam cleaner can also be used for decontaminating sampling equipment. Steam cleaning is the desired method since it does not introduce any additional chemicals into the system. If a steam cleaner is available it should be used instead of any other type of decontamination procedure. As with other procedures documented in this SOP, decontamination procedures may be determined by the client or regulatory agency involved in the project.

4.6 RECORDS AND DOCUMENTATION

4.6.1 Sample Designation

One suggested approach is to use the site name or an abbreviation or acronym of the site name to be the lead designator in the sample identification. For example, a sample from Hill Air Force Base Operable Unit 1 could be designated HAFB-OU1-2, with the final 2 designating the monitoring well number. Similarly, a spring sample may be designated with the site name HAFB-OU1-ZC, with the initials or name of the owner of the spring or name of the spring. Blind duplicate samples should be labeled with the number of a non-existent well. Equipment and trip blanks, collected when non-dedicated equipment is used, should also be labeled with a fictitious well name in a similar manner to the blind duplicate samples.

4.6.2 Sample Label

Sample containers should be labeled using water proof ink before a sample is obtained. A sample label should be affixed to all sample containers. This label identifies the sample by documenting the sample type, sampler(s) initials, sample location, time, date, analyses requested, and preservation method. A unique sample designation as discussed above is assigned to each sample collected. This sample ID is also noted on the sample label.

4.6.3 Field Notebooks and Sampling Forms

A field notebook should be prepared prior to beginning sampling activities and should be maintained throughout the sample round. The notebook should contain pertinent information about the monitoring wells, such as depth of casing and water levels. During sampling, all the activities should be recorded on a groundwater sampling log (see Attachment 2) and in the field notebook. All forms used during sampling should be referenced in the field notebook. A brief description of weather conditions should also be noted as weather can sometimes affect samples. Any deviation from the sampling procedure described in the project work plan or SOP should be outlined in detail and justified in the field notebook. Specialized sampling forms can also be used to record the field measurements and other conditions observed.

4.6.4 Chain-of-Custody

The chain-of-custody form (Attachment 3) should be used to record the number of samples collected and the corresponding laboratory analyses. Information included on this form consists of time and date sampled, sample number, type of sample, sampler's name, preservatives used, and any special instructions. A complete and separate COC form should be completed for each cooler. A copy of the COC form should be retained by the sampler prior to shipment (forms with multiple carbon copies are recommended). The original COC form should accompany the sample to the laboratory and provide a "paper trail" to track the sample. When transferring the possession of samples, the individuals relinquishing and receiving the samples should sign, date, and note the time on the chain-of-custody form.

4.7 SAMPLE HANDLING AND SHIPPING

4.7.1 Sample Handling

The samples will be kept cool during collection and shipment with regular ice contained in a plastic bag or with frozen "blue ice." It is suggested that the blue ice be changed immediately before shipment to help assure the samples remain cool. The samples should be stored in an appropriately sized, durable ice chest. Over a 3-inch layer of packing materials, such as vermiculite or bubble packaging, the samples should be placed and kept separated, with the intervening voids filled with the packing material more than halfway to the top of the bottles or containers. Bottles should be placed upright. The ice should be placed above and about the top of the containers. The chain-of-custody record should be sealed in a "Ziplock" plastic bag and affixed to the inside of the top lid of the cooler. The remaining space should be filled with packing material. The cooler should be secured by completely wrapping with strapping tape around both ends. If there is a drain on the cooler, it should be taped shut. Chain-of-custody seals should be affixed across the seal between the lid and body of the cooler.

4.7.2 Shipping Instructions

All samples should be shipped overnight delivery through a reliable commercial carrier, such as Federal Express, Emery, Purolator, or equivalent. If shipment requires more than a 24-hour period, sample holding times can be exceeded, or the samples may get warm compromising the integrity of the sample analysis. The sampler should call the laboratory to alert them when the samples will arrive on the following day.

5.0 REFERENCES

Jay, P.C., 1985. Anion Contamination of Environmental Water Samples Introduced by Filter Media. Analytical Chemistry 57(3): 780-782.

Nielson, D.M., 1991. Practical Handbook of Groundwater Monitoring, Lewis Publishers, Inc., Chelsea, MI.

Puls, R.W. and M.S. Barcelona, 1989. Ground Water Sampling for Metals Analyses, Superfund Ground Water Issue, EPA/540/4-89/001, March 1989.

U.S. Environmental Protection Agency (USEPA), 1986. RCRA Ground-Water Monitoring Technical Enforcement Guidance Document, OSWER-9950.1, September 1986.

6.0 ATTACHMENTS

1 – Monitoring Well Development/Sampling Form
2 - Groundwater Field Sampling Date Record
3 - Chain-of-Custody Record
4 - Volume of Schedule 40 PVC Pipe

Attachment 1 – Monitoring Well Development/Sampling Form

MWH
MONTGOMERY WATSON HARZA

MONITORING WELL SAMPLING LOG

PROJECT: ____________________

Well ID:	____________	Screened Interval (ft):	________	Well Diameter (in)	________
Date:	____________	Pump Depth (ft):	________	Static Water Level (ft):	________
Sample ID:	____________	Flow Rate (gpm)	________	Standing Water (ft):	________
Time:	____________	Purging Device:	________	One Well Volume (gal):	________
Analyses:	____________	Sampling Device:	________	OVA Reading at TOC:	________
QA/QC - Dup ID:	____________	Water Level Instrument:	________	OVA Reading in BZ:	________
Rinsate ID:	____________	Water Quality Meter(s):	________	Samplers Signature:	________

Time	Volume Purged (gal)	Flow Rate (gpm)	Water Level (feet - TOC)	SC (µS/cm)	pH	Temp	DO (mg/L)	Turbidity (NTU)	Other
			± 0.1 ft	5%	± 0.1	± 1°C	10%	< 10 NTU	
Final Field Parameter Measurements									

Comments: ____________________

Attachment 2 – Groundwater Field Sampling Record

MONTGOMERY WATSON PAGE ____ OF ____

PROJECT ____ JOB NO. ____

SAMPLE LOCATION I.D. ____ DATE ____ TIME START: ____ END: ____

WATER LEVEL / WELL DATA

WELL DEPTH ____ FT ☐ MEASURED ☐ HISTORICAL ☐ TOP OF WELL ☐ TOP OF CASING ☐ ____ CASING STICK-UP (FROM GROUND) ____ FT

WATER DEPTH ____ FT

WELL MATERIAL: ☐ PVC ☐ SS ☐ ____

WELL LOCKED? ☐ YES ☐ NO

WELL DIA. ☐ 2 INCH ☐ 4 INCH ☐ 6 INCH ☐ ____

WATER LEVEL EQUIP. USED: ☐ ELECT.COND.PROBE ☐ FLOAT ACTIVATED ☐ PRESS. TRANSDUCER ☐ ____

HEIGHT OF WATER COLUMN ____ FT x ☐ .16 GAL/FT (2 IN.) ☐ .65 GAL/FT (4 IN.) ☐ 1.5 GAL/FT (6 IN.) ☐ ___ GAL/FT (___ IN.) = ____ GAL/VOL ____ TOTAL GAL PURGED

WELL INTEGRITY:	YES	NO
PROT. CASING SECURE	☐	☐
CONCRETE COLLAR INTACT	☐	☐
OTHER ____	☐	☐

EQUIPMENT DOCUMENTATION

DECONTAMINATION METHOD:

PURGING/SAMPLING EQUIP. USED:

✓ IF USED FOR: PURGING	SAMPLING		EQUIPMENT I.D.
☐	☐	SUBMERSIBLE PUMP	____
☐	☐	STAINLESS STEEL BAILER	____
☐	☐	TEFLON/BAILER	____
☐	☐	____	____

SAMPLE

FIELD ANALYSIS DATA

AMBIENT AIR VOA ____ PPM WELL MOUTH ____ PPM FIELD DATA COLLECTED ☐ IN-LINE ☐ IN CONTAINER

PURGE DATA	@ ____ GAL	@ ____ GAL	@ ____ GAL	@ ____ GAL	@ ____ GAL
TEMPERATURE, DEG C					
pH, units					
SPECIFIC CONDUCTIVITY (umhos/cm. @ 25 deg.c)					
TURBIDITY, NTUs					

SAMPLE OBSERVATIONS: ☐ TURBID ☐ COLORED ☐ CLOUDY ☐ CLEAR ☐ ODOR

SAMPLE COLLECTION REQUIREMENTS

(✓ IF REQUIRED AT THIS LOCATION)

ANALYTICAL PARAMETER	✓ IF FIELD FILTERED	PRESERVATION METHOD	VOLUME REQUIRED	✓ IF SAMPLE COLLECTED	SAMPLE BOTTLE I.D.'S
☐				☐	____/____/____/____
☐				☐	____/____/____/____
☐				☐	____/____/____/____
☐				☐	____/____/____/____
☐				☐	____/____/____/____
☐				☐	____/____/____/____
☐				☐	____/____/____/____
☐				☐	____/____/____/____

NOTES:

SIGNATURE OF SAMPLER

Attachment 3 – Chain of Custody Record

MONTGOMERY WATSON HARZA — CHAIN OF CUSTODY RECORD — MWH CONTACT PERSON:

FED EX #: ____________ COOLER #: ____________ COC ID: ____________ LOGCODE: LAB:

SAMPLER(S) PRINTED NAME AND SIGNATURE

PROJECT NAME:
CLIENT ID
PROJECT NUMBER:

						ERPIMS CODES							ANALYSIS REQUEST											
SAMPLE ID	LOC ID	SBD	SED	DATE	TIME	SA	SN	SM	MC	BC	CT	PR												REMARKS

Comments/Instructions:

Note:

	Signature:	Print Name:	Company Name/Title:	Date:	
RELINQUISHED BY:			Montgomery Watson Harza		
RECEIVED BY:					
RELINQUISHED BY:					
RECEIVED BY:					

For Lab Use Only: Sample Condition Upon Receipt:

Legend
SBD: Sample Beginning Depth
SED: Sample Ending Depth

Sample Type Code (SA): From ERPIMS Handbook
Sample Number (SN): From ERPIMS Handbook
Sampling Method Code (SM): From ERPIMS Handbook
Sampling Matrix Code (MC): From ERPIMS Handbook

Bottle Count (BC): 1,2,3, etc.
Container Type (CT): S = Sleeve, A= Amber Glass, G = Clear Glass, P = Plastic, E = Encore sample
Preservative (PR): NA = None, A = HNO3, B = H2SO4, C = HCl, D = NaOH

ORIGINAL: Send with sample (sign only in blue or black ink) COPIES: Retained by Sampler, Sent to Office

Attachment 4 – Volume of PVC Pipe

Volume of PVC Casing				
Schedule	**Diameter**	**OD**	**ID**	**Volume/LF**
	Inches	**Inches**	**Inches**	**Gal.**
40	1.25	1.660	1.380	0.08
40	2	2.375	2.067	0.17
40	3	3.500	3.068	0.38
40	4	4.500	4.026	0.66
40	6	6.625	6.065	1.50
40	8	8.625	7.981	2.60
40	12	12.750	11.938	5.82
80	2	2.375	1.939	0.15
80	4	4.500	3.826	0.60

MWHA INDUSTRIAL GROUP AND FEDERAL GROUP
STANDARD OPERATING PROCEDURES

SOP-14
OPERATING AND CALIBRATION PROCEDURES
FIELD DOCUMENTATION

MWH
MONTGOMERY WATSON HARZA

MWHA INDUSTRIAL GROUP AND FEDERAL GROUP
STANDARD OPERATING PROCEDURES

SOP-14
OPERATING AND CALIBRATION PROCEDURES
FIELD DOCUMENTATION

TABLE OF CONTENTS

LIST OF ATTACHMENTS

1.0 INTRODUCTION

This Standard Operating Procedure is a general reference for the required documentation to be completed by company personnel during field investigations. Subject to the requirements of the contract, drecords in the form of field logbooks, reports, and forms should normally be completed for the various field activities. Records should be maintained on a daily basis as the work progresses, and should contain enough information to allow the Field Event to be completely reconstructed. All field records must be accurate, objective, and legible, because it is part of the client's product and may potentially serve as a legal document. As the field logbook is often the only record of the work conducted during the Field Event, it should normally be photocopied at least every week.

Sample field documentation forms are attached.

2.0 DEFINITIONS

None

3.0 RESPONSIBILITIES

All field team members are responsible for recording daily activities. An in-depth description of the documentation mentioned below is given in later sections.

The **Field Team Leader** (FTL) is responsible for completing the FTL logbook, Daily Quality Control Reports (DQCRs), documentation concerning supervision of team members, and duplication and distribution of applicable records.

The **Rig Geologist/Sampling Team** is responsible for completing the drilling logbook; lithologic logs; well construction diagrams; sampling documentation such as sample labels, sample register, and chain-of-custody (COC) forms.

The **Water Sampling/Development Team** is responsible for completing the water sampling/development logbook; groundwater sampling/development logs; and sampling documentation such as sample labels, sample register, and COC forms.

The **Aquifer Data Collection Team** is responsible for completing the aquifer logs (e.g., slug tests, step-drawdown tests, pump tests), water level records, and data organization/tracking (e.g., downloading of data from data loggers).

4.0 FIELD DOCUMENTATION GUIDELINES

Field documentation serves as the primary foundation for all field data collected that will be used to evaluate the project site. Field documentation must be accurate, legible, and written in indelible ink. Absolutely no pencils or erasures are to be used. Mistakes are to be crossed out with one line, dated, and initialed. Skipped pages or blank sections at the end of a page should be crossed out with an "X" covering the entire page or blank section, dated and initialed. The person making the correction should write "No Further Entries," and date and initial the page. The responsible field team member should sign and log the date and time after the last entry for the day. To further assist in the organization of the field books, logs, or forms, the date and the significant activity description (e.g., boring or well number) should be written at the top of each page. Each project job number should have its own field book. In addition, all original field documentation should be included with the project files.

The descriptions of field data and documentation given below serve as a guideline; individual projects will vary in documentation needs, depending on the circumstances surrounding the project and the needs of the client.

4.1 FIELD LOGBOOKS

The field logbook should be a bound, weatherproof book with consecutively numbered pages that serves primarily as a daily log of the activities carried out during the investigation. All entries should be made in indelible ink. A field logbook should be completed for each operation undertaken during the investigation, such as field team leader notes, drilling, groundwater sampling/development, and site visitors. The logbook serves as a diary of the events of the day.

Field activities will vary from project to project; however, the concept and general information to be recorded will be generally consistent. The following sections describe the minimum information that should normally be recorded in the three logbooks in which field activities are documented.

FTL Logbook

The FTL's responsibilities include the general supervision, support, assistance, and coordination of the various field investigation activities. A large portion of the FTL's day is spent rotating between operations in a supervisory role. Records of the FTL's activities, as well as a summary of the field team's activities, are maintained in a logbook. The FTL's logbook will be used to fill out DQCRs, and as such should contain all information required in these reports (Section 3.3). Items to be documented include the following:

- Record of tailgate meetings
- Personnel and subcontractors on job site and time spent on the site
- Field operations and personnel assigned to these activities
- Site visitors
- Log of the FTL's activities—time spent supervising each operation and summary of daily operations as provided by field team members
- Problems encountered and related corrective actions
- Deviations from the sampling plan
- Records of communications—discussions of job-related activities with the client, subcontractor, field team members, and project manager
- Information on addresses and contacts
- Record of invoices signed and other billing information
- Field observations

Rig Geologist/Sampling Team Logbook

The rig geologist or sampling team leader is responsible for recording the following information:

- Health and safety activities
  - Calibration records for health and safety equipment (type of photoionization detector (PID), calibration gas used and associated readings, noise dosimeters, etc.)
  - Personnel contamination prevention and decontamination procedures
  - Record of daily tailgate safety meetings
- Weather
- Calibration of field equipment
- Equipment decontamination procedures
- Personnel and subcontractors on the job site and time spent on the site
- Site name and well or soil boring number
- Drilling activities
  - Sample location (sketch)
  - Drilling method and equipment used
  - Borehole diameter
  - Drill cuttings disposal/containerization (number of drums, roll off-bins, etc.)
  - Type and amount of drilling fluids used (mud, water, etc.)
  - Depth and time at which first groundwater was encountered, depth to water at completion of drilling, and the stabilized depth to water—absence of water in the boring should also be noted
  - Total drilling depth of well or soil boring
  - Type and amount of materials used for well installation
  - Well construction details—depth of grout (mixture, weight), bentonite seal, filter pack, etc. (include type and amount used, calculate estimated amount that should be used)
  - Type and amount of material used to backfill soil borings
  - Time and date of drilling, completion, and backfilling
  - Name of drilling company, driller, and helpers
- Sampling
  - Date and time of sample collection
  - Sample interval
  - Types of samples taken

- Number of samples collected
- Analyses to be performed on collected samples

- Disposal of contaminated wastes (personal protective equipment, paper towels, Visqueen®, etc.)
- Field observations
- Problems encountered and corrective action taken
- Deviations from the sampling plan
- Site visitors

Groundwater Sampling/Development Logbook

The groundwater sampling and development team members are responsible for recording the following information:

- Health and safety activities
  - Calibration records for health and safety equipment (i.e., type of PID, calibration gas used and readings, noise dosimeters etc.)
  - Personnel contamination prevention and decontamination procedures
  - Record of daily tailgate safety meetings
- Weather
- Calibration of field equipment
- Equipment decontamination procedures
- Personnel and subcontractors on job site and time spent on the site
- Equipment decontamination procedures
- Disposal of contaminated wastes (personal protective equipment, paper towels, Visqueen®, etc.)
- Site name and well number
- Water levels and product levels—time and datum that water levels are measured (i.e., top of casing); purging of the well (include calculations, well volumes) with the following information:

  - Measured field parameters (temperature, pH, conductivity, odor, color, cloudiness, etc.)
  - Amount of water purged
  - Purge method—indicate bailer/pump, diameter and length of bailer, material that the bailer is composed of, type of pump, new nylon rope, etc.

- Purge water disposal and containment (Baker tank/ drums, number used, identification, etc.)

- PID readings from inside of well, purged water, and breathing zone

- Background PID readings

- Well sampling

  - Number of samples collected and type of containers used
  - Date and time of sample collection
  - Type of analyses
  - QA/QC samples collected; names given to blind samples

- Field observations

- Problems encountered and corrective actions taken

- Deviations from the sampling plan

- Site visitors

4.2 TAILGATE SAFETY MEETINGS

Tailgate safety meetings are held at the beginning of each day before the start of work. All personnel, subcontractors, and others who will be on the job site are required to attend. The meetings are usually conducted by the FTL, on-site safety officer, or other qualified team member. The topics discussed at the meeting include the following:

- Directions to the hospital
- Protective clothing and equipment
- Chemical hazards
- Physical hazards
- Special equipment
- Emergency procedures

- Emergency phone numbers

All site personnel are required to sign the tailgate safety meeting form. The original form is kept on site, and a copy sent to the home office.

4.3 DAILY QUALITY CONTROL REPORTS

The preparation of DQCRs is the responsibility of the FTL. DQCRs are completed on a daily basis to summarize the events of the day and supplement the information that is already recorded in the field logbook. DQCRs should be completed regardless of the duration of the field effort. Depending on the client, copies of the report are distributed to the MWH Project Manager, MWH Project Geologist, Client Project Manager (depending on the project), field office file, and home office file. Information recorded in this report should include the following.

- Date and weather information—date, daily temperatures, wind speed and direction, humidity
- MWH personnel and time spent on site
- Subcontractors and time spent on site
- Special equipment on site—PID, Smeal water sampling rig, hollow-stem auger Rig, pH meter, conductivity meter, etc.
- Work and sampling performed—personnel performing specific site activities, a summary of samples collected, and a thorough explanation of the work completed
- Quality control activities—e.g., decontamination procedures, QA/QC samples taken, calibration of field equipment
- Health and safety levels and activities—field parameter measurements, including calibration of equipment; daily tailgate safety meetings, level of protection used, etc.
- Problems encountered/corrective actions taken—any technical difficulties (e.g., problems encountered during drilling or equipment breakdowns); any problems that could potentially affect the quality of the samples should be included
- Special notes—any information that does not fit under the categories listed above, but is important to record; information that would be useful for future sampling, (e.g., base contacts made, visitors on site, etc.)

- Next day activity expectations
- Date/Signature of individual completing the report

4.4 BORING LOGS

The preparation of drill logs is the responsibility of the field team members assigned to the drill rig. A detailed description of well logging is provided in the SOP for Lithologic Logging, SOP-17. Several examples of drilling logs are given in the attachments for SOP-17. The exact format depends on the job and the client; however, the following basic information should normally be recorded on the log regardless of the format:

- Project and site name
- Name of driller and drilling company
- Type of drill rig used
- Drill rig contamination procedures
- Well/soil boring ID and location (sketch)
- Drilling and backfilling dates and times
- Reference elevation for all depth measurements
- Total depth of completed soil boring/well
- Depth of grouting, sealing, and grout mixes
- Signature of the logger.
- Description of unconsolidated materials
    - Geologic lithology description
    - Descriptive Unified Soil Classifications System (USCS) classification
    - USCS symbol
- Color (use appropriate soil color chart)
    - Penetration resistance (consistency or density)
    - Moisture content
    - Grain size information
    - Miscellaneous information (odor, fractures, visible contamination, etc.)
- Description of consolidated materials
    - Geologic rock description
    - Rock type

- Relative hardness
- Density
- Texture
- Color (use appropriate rock color charts)
- Weathering
- Bedding
- Structures (fractures, joints, bedding, etc.)
- Miscellaneous information (presence of odor, visible contamination, etc.)

- Stratigraphic/lithologic changes; depths at which changes occur
- Depth intervals at which sampling was attempted and amount of sample recovered
- Blow counts
- Depth intervals from which samples are retained
- Analyses to be performed on collected samples
- Depth at which first groundwater was encountered, depth to water at completion of drilling, and the stabilized depth to water. The absence of water in the boring should also be noted.
- Loss and depth of drilling fluids, rate of loss, and total volume of loss
- Use of drilling fluids
- Drilling and sampling problems
- PID readings

4.5 WELL CONSTRUCTION DIAGRAMS

The preparation of well construction diagrams is also the responsibility of field team members assigned to the drilling operations. This topic is further discussed in the SOP for Well Installation, SOP-02. The exact format of the diagram is dependent on the job and the client; however, the following basic information should be recorded and/or illustrated on the diagram regardless of the format.

- Project and site name
- Well identification number

- Name of driller and drilling company
- Depth and type of well casing
- Description of well screen and casing
- Borehole diameter
- Any sealing off of water-bearing strata
- Static water level upon completion of the well and after development
- Drilling and installation dates
- Type and amount of annulus materials used; depth measurements of annulus materials
- Other construction details (filter pack type and interval, location of centralizers, etc.)
- Surface elevation and reference elevation of all depth measurements

4.6 GROUNDWATER SAMPLING AND DEVELOPMENT LOGS

The groundwater sampling and development log should be used any time a well is developed or sampled. The following information should be recorded on the log.

- Project name and site
- Well identification number
- Equipment decontamination procedures
- The date and time of sampling or development
- The water level and reference elevation
- Volume of water to be purged
- Pertinent well construction information (total depth, well diameter, etc.)
- Measurement of field parameters such as pH, turbidity, conductivity, and temperature, as well as the times at which the readings were taken.
- Type of purging and sampling equipment used
- Type of samples collected

- Sampler's initials

4.7 AQUIFER TESTING LOGS

The aquifer testing team is responsible for setting up, collecting, tracking, and organizing data. The information listed below should normally be included. The Aquifer Testing SOP-04 contains more details and the various book references related to the project site.

- Well number/identification (data logger identification)
- Data logger information/parameter setup
- Water level (include date, time, and measurement reference (such as top of casing)
- Type of aquifer test (slug, step-drawdown, pump test, etc.)
- Slug test (include length and diameter of slug for volume calculations)
- Start time of test
- Duration of test
- Pump tests (include disposal/containment of water information)
- Field observations and problems
- Tester's name

4.8 DOCUMENTATION OF SAMPLING ACTIVITIES

Documentation to be made during sampling activities includes sample labels, sample seals, chain-of-custody records, airbill and identification of courier, and sample register.

4.8.1 Sample Labels

A sample label, written in indelible ink, should be affixed to all soil and water sample containers. Required information on sample labels may vary from job to job; however, the following should be included at a minimum:

- Sample number
- Type of sample (grab or composite)
- Type of preservative, if applicable
- Date and time of collection
- Project location
- Analyte(s)

- Initials of sampling personnel

4.8.2 Custody Seals

Custody seals consist of security tape with the initials of the sampler and the date placed over the lid of each cooler containing samples. The tape should be placed such that the seal must be broken to gain access to the contents. Custody seals should not be placed directly onto the volatile organic compound (VOC) sample bottles. Custody seals should be placed on coolers prior to the sampling team's release to a second or third party (e.g., shipment to the laboratory).

4.8.3 Chain-of-Custody Records

Chain-of-custody procedures allow for the tracing of possession and handling of individual samples from the time of field collection through laboratory analysis. The chain-of-custody is documented through a record that lists each sample and the individuals responsible for sample collection, shipment, and receipt. A sample is considered in custody if it is any of the following:

- In a person's possession.
- In view after being in physical possession.
- Locked or sealed so that no one can tamper with it after it has been in an individual's physical custody.
- In a secured area, restricted to authorized personnel.

A COC record is used to record the samples taken and the analyses requested. It is the legal record for maintaining accountability of control over the sample. Information recorded includes time and date of sample collection, sample number, and the type of sample, the sampler's signature, the required analysis, and the type of containers and preservatives used. A copy of the COC record should be retained by the sampler prior to release to a second or third party. Shipping receipts should be signed and filed as evidence of custody transfer between field sampler(s), courier, and laboratory.

The COC record will be properly signed and the date of collection and shipment recorded, along with the sample site identifications and requested analyses for each sample.

4.8.4 Sample Register

The sample register is a field record book with consecutive prenumbered pages. A full description of each sample is recorded in the book. The information included in the sample register should include the following:

- Sample number (identification)
- Duplicate and split sample numbers (identification)
- Location of sample
- Client
- Project number
- Collection method
- Number and size of bottles for each analysis
- Destination of the sample
- Type of analysis
- Date and time of collection
- Name of sampler

Other observations may be included as the situation dictates for a thorough record that could be used to reconstruct the events concerning that sample. All information must be recorded in indelible ink. Mistakes are to be crossed out with one line, dated, and initialed. Skipped pages or blank sections at the end of a page should be crossed out with an "X" covering the entire page or blank section, dated and initialed.

5.0 REFERENCES

None.

ATTACHMENT 1

TAILGATE SAFETY FORMS AND HEALTH AND SAFETY DOCUMENTATION

TAILGATE SAFETY MEETING FORM

Location: ____________________ **Date:** __________

SAFETY TOPICS PRESENTED

PROTECTIVE CLOTHING/EQUIPMENT: Safety glasses, steel toed boots, boot cover, and nitrile gloves and liners during soil and groundwater sampling. Tyvek coveralls or dedicated work clothes with long sleeves will be worn during all soil and groundwater sampling. Leather gloves are recommended when handling tools. Hard hat is required. Sunscreen or other sun protection is highly recommended.

CHEMICAL HAZARDS:

PHYSICAL HAZARDS: Slip, trip and fall. Wet and slippery surfaces and heavy vegetation. Poisonous snakes. Heavy lifting. Base traffic. Heat stress.

SPECIAL EQUIPMENT:

OTHER: Maintain an exclusion zone with stakes and caution tape. Restrict entry of site visitors. No eating, drinking, smoking, or chewing in the exclusion zone.

EMERGENCY PROCEDURES: First aid kit and fire extinguisher are in equipment kit. Apply first aid and stabilize victim. Transport to medical center. Attach route to hospital or medical center.

EMERGENCY INFORMATION: In case of immediate danger to life or limb, call the ________________ Medical Facility at ______________________________.

Attendees:	Name (print)	Name (Signature)
	______________________	______________________
	______________________	______________________
	______________________	______________________
	______________________	______________________
	______________________	______________________
Conducted by:	______________________	______________________

ATTACHMENT 2

DAILY QUALITY CONTROL REPORTS

MONTGOMERY WATSON

DAILY QUALITY CONTROL REPORT

Date: ______________________________

MW PM: ___________________________

Location: __________________________

Project: ___________________________

Job Number: ________________________

Contract Number: ____________________

Report No: ______________________

Day: __________________________

Weather: _______________________

Temp: __________________________

Wind: __________________________

Humidity: _______________________

PERSONNEL ON SITE:

EQUIPMENT ON SITE:

WORK PERFORMED (INCLUDING SAMPLING):

Project: ____ Report No: ______
Job No: ____ Date: ___________

QUALITY CONTROL ACTIVITIES (INCLUDING FIELD CALIBRATIONS):

HEALTH AND SAFETY LEVELS AND ACTIVITIES:

PROBLEMS ENCOUNTERED AND CORRECTIVE ACTION TAKEN:

SPECIAL NOTES:

TOMORROW'S EXPECTATIONS:

Prepared by: __________________ Title: _______________

Distribution:
1. Client Manager
2. Base POC
3. MW Project Manager
4. MW Contract Manager
5. Field Office
6. Project File

ATTACHMENT 3

LITHOLOGIC LOGS

MONTGOMERY WATSON

Boring #: MW#: Sheet 1 of	
Project:	
Job #: Site:	
Logged By: Reviewed By:	
Drilling Contractor:	
Drill Rig Type/Method:	
Drillers Name:	
Borehole Diam./Drill Bit Type:	Total Depth
	Ref. Elev.
Site Sketch Map	Sampler Type:
Depth to 1st Water (▽): Time/Date:	Drill Start Time/Date: Drill Finish Time/Date:
Depth to Water After Drilling (▼): Time/Date:	Well Completion Time/Date:
Depth to other Water Bearing Zones:	Soil Boring Backfill Time/Date:

PID/OVA	Sample Interval	Recovered (in.)	Blow Counts / 6 in.	Retained for Analysis	Casing Type & Size	Annulus Filler	Depth (Feet)	USCS Soil Type	Soil Description	Estimated % Of Gravel	Sand Coarse	Sand Medium	Sand Fine	Silt/clay
							1							
							2							
							3							
							4							
							5							
							6							
							7							
							8							
							9							
							10							
							11							
							12							

QA/QC

Boring #: MW#: Project: Sheet of

PID/OVA	Sample Interval	Recovered (in.)	Blow Counts / 6 in.	Retained for Analysis.	Casing Type & Size	Annulus Filler	Depth (Feet)	USCS Soil Type	Soil Description	Estimated % Of				
											Sand			
										Gravel	Coarse	Med.	Fine	Silt/Clay
							2							
							3							
							4							
							5							
							6							
							7							
							8							
							9							
							0							
							1							
							2							
							3							
							4							
							5							
							6							
							7							
							8							
							9							
							0							
							1							
							2							

QA/QC

ATTACHMENT 4

WELL CONSTRUCTION LOGS

BORING NO. __________

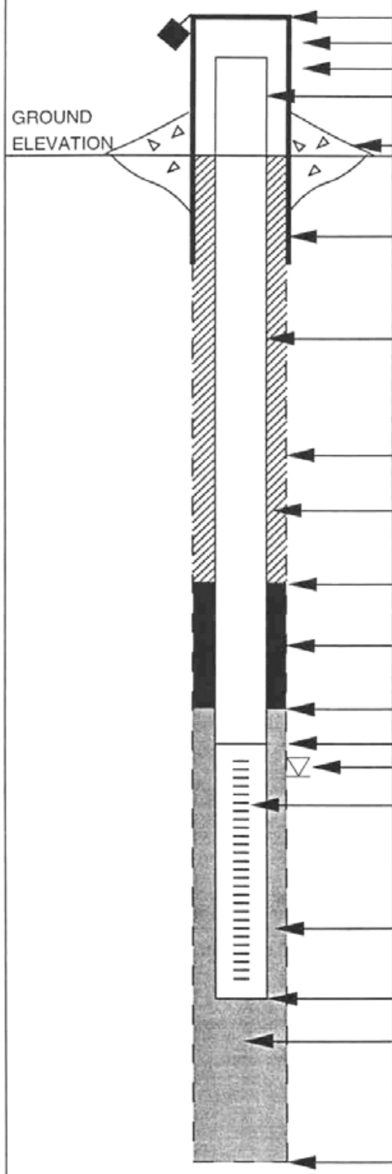
MONITORING WELL SHEET

PROJECT ______________________ LOCATION ______________________ DRILLER ______________________

PROJECT NO. ______________________ BORING ______________________ DRILLING METHOD ______________________

ELEVATION ______________________ DATE ______________________ DEVELOPMENT METHOD ______________________

FIELD GEOLOGIST ______________________



ELEVATION OF TOP OF SURFACE CASING: __________

ELEVATION OF TOP OF RISER PIPE: __________

STICK - UP TOP OF SURFACE CASING: __________

STICK - UP RISER PIPE: __________

TYPE OF SURFACE SEAL: ______________________

I.D. OF SURFACE CASING: ______________________

TYPE OF SURFACE CASING: ______________________

RISER PIPE I.D.: ______________________

TYPE OF RISER PIPE: ______________________

BOREHOLE DIAMETER: ______________________

TYPE OF BACKFILL: ______________________

ELEVATION / DEPTH OF SEAL: __________

TYPE OF SEAL: ______________________

DEPTH TOP OF SAND PACK: __________

ELEVATION / DEPTH TOP OF SCREEN: __________

FIRST ENCOUNTERED SATURATED ZONE

TYPE OF SCREEN: ______________________

SLOT SIZE x LENGTH ______________________

I.D. OF SCREEN ______________________

TYPE OF SAND PACK: ______________________

ELEVATION / DEPTH BOTTOM OF SCREEN: __________

ELEVATION / DEPTH BOTTOM OF SAND PACK: __________

TYPE OF BACKFILL BELOW OBSERVATION WELL: ______________________

ELEVATION / DEPTH OF HOLE: __________

MWH
MONTGOMERY WATSON HARZA

WELL DEVELOPMENT LOG

Well ID:	______	**Screened Interval (ft):**	______	**Well Diameter (in)**	______
Date:	______	**Pump Depth (ft):**	______	**Static Water Level (ft):**	______
Sample ID:	______	**Flow Rate (gpm)**	______	**Standing Water (ft):**	______
Time:	______	**Purging Device:**	______	**One Well Volume (gal):**	______
Method:	______	**Water Level Instrument:**	______	**OVA Reading at TOC:**	______
Technician:	______	**Water Quality Meter(s):**	______	**OVA Reading in BZ:**	______

Time	Volume Purged (gal)	Flow Rate (gpm)	Water Level (feet - TOC) ± 0.1 ft	SC (µS/cm) 5%	pH ± 0.1	Temp ± 0.1 °C	ORP (mV) 5%	Turbidity (NTU) < 10 NTU	Other	Comments
Final Field Parameter Measurements										

Comments: ______

ATTACHMENT 6

AQUIFER TESTING FORMS

ATTACHMENT 7

SAMPLING DOCUMENTATION AND TRACKING FORMS

Sample Tracking and Documentation Form

Project: ______________________________ **Site:** ______________________________

Location ID	Sample ID	Method	Matrix	Date Sampled	Time Sampled	Date Shipped	Cooler No.	Lab Dest.	Fedex Tracking No.	QA/QC Samples

Field Duplicates:

Splits (LIMS # _______________):

Page 1

Sample Tracking and Documentation Form

Project: ______________________________ **Site:** ______________________________

Location ID	Sample ID	Method	Matrix	Date Sampled	Time Sampled	Date Shipped	Cooler No.	Lab Dest.	Fedex Tracking No.	QA/QC Samples

Equipment Rinsate Blanks:

Equipment Rinsate Blanks Splits (LIMS #____________):

Trip Blanks

QA/QC CODES:

1 = Primary Lab Duplicate
2 = Primary Lab Duplicate and QA Laboratory Split
3 = Primary Lab Rinsate Blank
4 = Primary Lab Rinsate Blank and QA Lab Rinsate Blank Split
5 = Matrix Spike and Duplicate (MS/MSD)

MWH
STANDARD OPERATING PROCEDURES

SOP-15
FIELD LOGBOOK

MWH
MONTGOMERY WATSON HARZA

STANDARD OPERATING PROCEDURES

SOP-15
SITE LOGBOOK

TABLE OF CONTENTS

1.0 INTRODUCTION

The field logbook is a controlled document that contains information about all major on-site activities associated with investigation and remediation projects. The field logbook serves as the primary documentation of all field activities and events. Information recorded in the field logbook is described in Section 4.0, Methods. Site-specific procedures described in project work plans supersede this Standard Operating Procedure (SOP). Some site conditions and/or client requirements may necessitate deviations from this SOP.

The site logbook is initiated at the start of the first on-site activity (e.g., initial reconnaissance survey or site walk). Entries are made each day field activities occur. The site logbook is part of the permanent project file maintained by MWH, and is submitted to the project manager, who sends it to the project file at the completion of field activities. The site logbook may be admitted as evidence in cost recovery or other legal proceedings, so it is critical that this document be properly maintained.

2.0 DEFINITIONS

Field Logbook	The field logbook (also called field notebook) is a bound, waterproof notebook with consecutively numbered pages that cannot be removed.

3.0 RESPONSIBILITIES

Field logbooks are issued to field team members by the field team leader (FTL) or Project Manager. Each field team member in possession of a field logbook is responsible for keeping it current, accurate, straightforward, and relevant (see Section 4.0, Methods), and for submitting the field logbook to the FTL or Project Manager when the field work is completed. The Project Manager or designee reviews the field logbook for completeness, legibility, and relevance at the end of the field effort.

4.0 METHODS

During each field day, all site activities, personnel, visitors, and problems are recorded in the field logbook. The following paragraphs include lists of types of information included, when applicable, and methods for maintaining the field logbook.

The cover of each site logbook contains the following information:

- project name
- client name
- MWH project number
- project manager's name
- applicable work plan (s)
- sequential book number
- start date
- end date

The beginning of each daily entry includes the following:

- date
- day of week
- location
- PPE level
- start time
- weather
- personnel
- subcontractors
- visitors
- equipment
- MWH job number and cost code for that day's activities

Daily site logbook entries include but are not limited to the following, as applicable:

.

- arrival and surveying, decontamination, inspection, or other field activity
- equipment calibration

- materials used
- sampling activities and methods
- sample numbers, dates, times, locations, and analyses
- sketches of work locations, sample locations, excavations, etc.
- sketches of well construction details
- sample shipment information (chain-of-custody form numbers, carrier, time)
- start and completion times of each work activity
- storage and disposal of wastes
- field measurements
- health and safety issues (PPE level, time of tailgate safety meeting, etc.)
- unusual events
- accidents and near misses
- work progress
- work problems
- corrective actions
- variations from project plans or standard procedures
- communication with the client or others
- communication with the project manager or other MWH staff
- references to other project logs (purge, sample, equipment calibration, QC, photograph, equipment, borehole, construction, development, etc.)

Because the site logbook and its contents are admissible as evidence in legal proceedings, the following guidelines are also important:

- Unnecessary or irrelevant information or opinions are not recorded.
- Language used in the site logbook is always professional.
- Pages are not removed from the site logbook.
- All entries are in waterproof blue or black ink.
- The person entering information signs each page on which information is recorded.
- Blank portions of pages, and pages that have been inadvertently left blank, are crossed out and signed.
- The words "End of Day" and the signature of the person making the entry appear at the end of each daily entry.

- The field logbook is reviewed and signed by the FTL or Project Manager when the field work is completed.

APPENDIX B

FIELD FORMS